POSTGLACIAL RECONSTRUCTION OF FIRE HISTORY FROM A SMALL LAKE IN SOUTHWEST YUKON USING SEDIMENTARY CHARCOAL AND POLLEN

by

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ABSTRACT

Previous research suggests climate warming during the current century is likely to lead to an increase in the frequency and severity of wildfire. Recent wildfire seasons in northern Canada generally support these studies, with some of the worst fire seasons on record occurring during the past few years. While we can readily track the spatial and temporal distribution of these events during recent decades using satellite-derived data, the historical records of past fire activity are relatively short. Proxy records of past fire activity are needed to fully understand how fire regimes may be shifting in response to the changing climatic conditions. A high-resolution fire record, dating back to the early Holocene, has been reconstructed using a 512-cm sediment core collected from a small lake in southwest Yukon. Macroscopic charcoal was counted throughout the core at 0.5-cm contiguous intervals. The core was also analyzed for loss-on-ignition and magnetic susceptibility. Fossil pollen preserved in the lake sediment was analyzed to determine vegetation change throughout the Holocene. Results indicate an average signal to noise index of 6.2, suggesting the peaks are significant and detectable from the slowly varying background level and the record is suitable for peak detection. Macroscopic charcoal analysis indicates an active fire history throughout the record, with 90 fires occurring throughout the Holocene. Results suggest the fire regime in this region responds to both top-down (climate) and bottom-up (vegetation) factors. Fire return intervals changed in response to shifts in precipitation and temperature as well as the expansion of lodgepole pine into the region. The shifts in precipitation and temperature were attributed to the oscillation of the Aleutian Low pressure system and fluctuations in climate associated with the Medieval Climate Anomaly and the Little Ice Age.

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LIST OF ACRONYMS

AL	Aleutian low
AMS	Accelerator mass spectrometry
BaP	Benzo(a)pyrene
bCHAR	Background charcoal
CHAR	Charcoal accumulation rates
CIC	Constant initial concentration
CO_2	Carbon dioxide
C_{Peak}	Significant peaks in charcoal concentration
CRS	Constant rate of supply
DW_{110}	Weight after drying at 110°C
DW_{550}	Weight after burning at 550°C
DW_{950}	Weight after burning at 950°C
ENSO	El-Nino southern oscillation
FRI	Fire return interval
GCM	General circulation model
GMCD	Global modern charcoal database
IPCC	Intergovernmental panel on climate change
LIA	Little Ice Age
LOI	Loss-on-ignition
$_{m}$FRI	Mean fire return interval
MS	Magnetic susceptibility
MCA	Medieval Climate Anomaly

MCMC	Markov chain Monte Carlo
NR	Non-transform residual model
PAH	Polycyclic aromatic hydrocarbon
PDO	Pacific decadal oscillation
SNI	Signal-to-noise index
SST	Sea surface temperature
$\mathbf{W_{Wet}}$	Wet weight
WRA	White River ash
yr BP	Years before present
$\mathbf{^{14}C}$	Radioactive carbon isotope
$\mathbf{^{210}Pb}$	Radioactive lead isotope

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Atmospheric greenhouse gas concentrations are higher than they have ever been in the past 800,000 years and global mean surface temperatures continue to rise (IPCC, 2014). As atmospheric greenhouses gases and mean global temperatures continue to increase, ecosystem processes such as disturbance regimes are being altered (Overpeck et al., 1990). In boreal ecosystems, the most prominent disturbance agent is wildfire. As climate change alters these natural disturbances the frequency and severity of wildfire is likely to increase (Flannigan et al., 2013). While the socioeconomic impacts (i.e., damage to infrastructure, health related issues associated with prolonged air quality issues) of wildfire are generally negative, the environmental impacts of wildfire are often beneficial. Wildfires can degrade air and water quality over short timescales (days, months, years and possibly decades), but also have longer-term beneficial impacts such as increasing soil nutrients, resetting successional pathways and increasing biodiversity in older successional stands (Mustaphi and Pisaric, 2014).

Over the past 25 years, wildfires in Canada have burned an average of 2.3 million ha a year, and fire management costs range from $500 million to $1 billion (Natural Resources Canada, 2016). Forest managers are faced with difficult decisions of trying to balance the ecological benefits of fire while also limiting any potential damage and costs associated with fire to public and private infrastructure. As wildfire is the dominant disturbance agent in boreal ecosystems, it is important to fully understand fire regimes across boreal regions of Canada.

Warming atmospheric temperatures during recent decades are likely increasing the frequency and severity of wildfire. Notably, intense wildfire in northern Canada during recent years has generated major concerns of how stakeholders will cope with associated health concerns and other negative impacts of wildfire in the future. General circulation models (GCMs) have been used to predict future wildfire severity and the length of the fire season under different emissions scenarios (low, medium and high) (Flannigan et al., 2013). Results indicate that under all emission scenarios there will be significant increases in fire season length as well as fire frequency and severity by the end of the 21st century, with the greatest increases occurring in the Northern Hemisphere. If these projections of future wildfire activity are realized, these increases in wildfire activity would likely make current fire management practices ineffective and the increasing financial burden will likely exceed budgets and available resources.

Historical records of past fire activity are relatively short. Therefore, proxy records of past fire activity are needed to fully understand how fire regimes have changed in the past to identify how they might change in the future. As the magnitude and frequency of wildfire is highly variable over space and time, paleo-fire records can provide a longer timeframe to investigate the relationship between fire, climate and vegetation. The longer paleo-fire records can also provide a more accurate assessment of the natural variability that is inherent in disturbance regimes. Records of fire activity from the 20th century are often impacted by fire suppression activities. Therefore, the paleo-fire record can provide insights into fire activity during eras that predate fire suppression efforts. This increased knowledge of fire regimes will help determine if current fire regimes are within the range of natural variability and to assess the time between fires with and without fire suppression. Overall, increased knowledge of long-term fire history can help make forest management practices more responsive to the impacts of climate change on northern forests and the fire regime.

1.2 Objectives

The main objective of this study was to create a high-resolution record of fire activity for southwest Yukon using paleolimnological techniques. This paleo-fire record was reconstructed using macroscopic charcoal preserved in the lake sediment collected from a small lake in southwest Yukon and informally named Spindly Pine Lake (unofficial name). Based on the paleo-fire record, three additional objectives are identified: 1) to determine the total number of fires throughout the Holocene and the time between fires to analyze the temporal change in fire return intervals (FRIs); 2) identify when lodgepole pine arrives in the region based on the analysis of subfossil pollen preserved in the lake sediment and determine if this change in dominant vegetation cover altered the fire regime and 3) determine the major climatic drivers of fire in the region.

1.3 Thesis Format

This thesis follows the integrated article format. Following this introductory chapter (Chapter 1) will be an extensive literature review in Chapter 2. This literature review contains background information on paleolimnology, including coring and dating techniques, information on fire history reconstructions, discussion of fire behaviour, and current knowledge of wildfire in Yukon. Finally, Chapter 2 will conclude with the current and future impacts climate change may have on wildfire. Chapter 3 is the main research chapter and includes the research findings. The chapter is formatted as a stand-alone manuscript that will be submitted for publication in a peer-reviewed journal. Chapter 4 provides conclusions and makes future recommendations. Appendices following the body of this thesis include a detailed methodology, supplemental figures, and raw data.

REFERENCES

Flannigan, M., Cantin, A. S., de Groot, W. J., Wotton, M., Newbery, A., & Gowman, L. M. (2013). Global wildland fire season severity in the 21st century. *Forest Ecology and Management*, 54-61.

IPCC, 2014: Summary for Policymakers, *In: Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer,O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B.Kriemann, J. Savolainen, S. Schl.mer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Mustaphi, C. C., & Pisaric, M. F. (2014). Holocene climate-fire-vegetation interactions at a subalpine watershed in southeastern British Columbia, Canada. *Quaternary Research*, 228-239.

Natural Resources Canada. (2016). *Boreal Forest*. Retrieved from https://www.nrcan.gc.ca/forests/boreal/13071

Overpeck, J. T., Rind, D., & Goldberg, R. (1990). Climate-induced changes in forest disturbance and vegetation. *Nature*, 51.

CHAPTER TWO

LITERATURE REVIEW

2.1 Terminology

There are several key components and terms related to wildfire and fire history that are important to understand and distinguish. Stocks et al. (2003) refer to the fire regime as all the characteristics that comprise fire which include: fire frequency, fire return interval (FRI), size, intensity, type and severity. Fire frequency is the average number of fires over a certain period of time and a FRI is the time required for a certain sized area to reburn (Edwards et al, 2015). Fire size indicates the amount of land or vegetation that is effected. Fire intensity refers to the amount of energy that is released and severity refers to the amount of fuel burned during a fire (DeBano et al., 1998 & Stocks et al, 2003).

2.2 Paleoecology and Lake Sediments

Paleoecology research is focused on past ecosystems and uses lake sediment to gain understanding of the previous environmental conditions (Cohen, 2003). Although its roots lie in ecology, paleoecology and ecology have evolved separately as disciplines (Rull, 2010). The diverse discipline of paleoecology aims to achieve many different goals through many scientific lenses, such as biology and geology. There are a number of sub-disciplines within paleoecology, including paleolimnology, which has grown and advanced quickly in recent decades as shown by the success of the Journal of Paleolimnology since its inception in 1988. As we move into the Anthropocene, where humans are becoming the major driver of environmental change, the field of paleoecology is increasing in importance as it can provide information about past conditions over long timescales (e.g., the Holocene epoch or even longer). Paleoecology can also provide evidence as to how current conditions are changing and potentially exceeding previous norms. The utility of paleolimnology lies in the analyses of combined high-resolution records of parameters measured from sediments, which provide a reconstruction of historical landscape and climate change (Cohen, 2003).

The approach behind paleolimnology is relatively simple. As sediments accumulate at the bottom of a lake basin, they settle in an ordered and undisturbed manner. Over time lakes receive inputs from many different sources. Allochthonous material is derived from outside of the lake and includes biotic and abiotic inputs such as pollen and spores, charcoal particles, volcanic ash, nutrients (phosphorus and nitrogen) inorganic minerals and pollutants. Conversely, autochthonous inputs originate within the lake itself and include bacteria, algae and chironomids (Figure 2.1). These different inputs accumulate in undisturbed basins over time and can be analyzed by a paleolimnologist to develop proxy records of climate and environmental change (Smol et al., 2001 & Cohen, 2003). With such a large number of proxy indicators, the range of questions that can be studied is immense. Therefore, as the discipline has evolved, the many paleoecological methods and approaches have been standardized to help analyze the sediments in a rigorous and repeatable way (Smol et al., 2012).

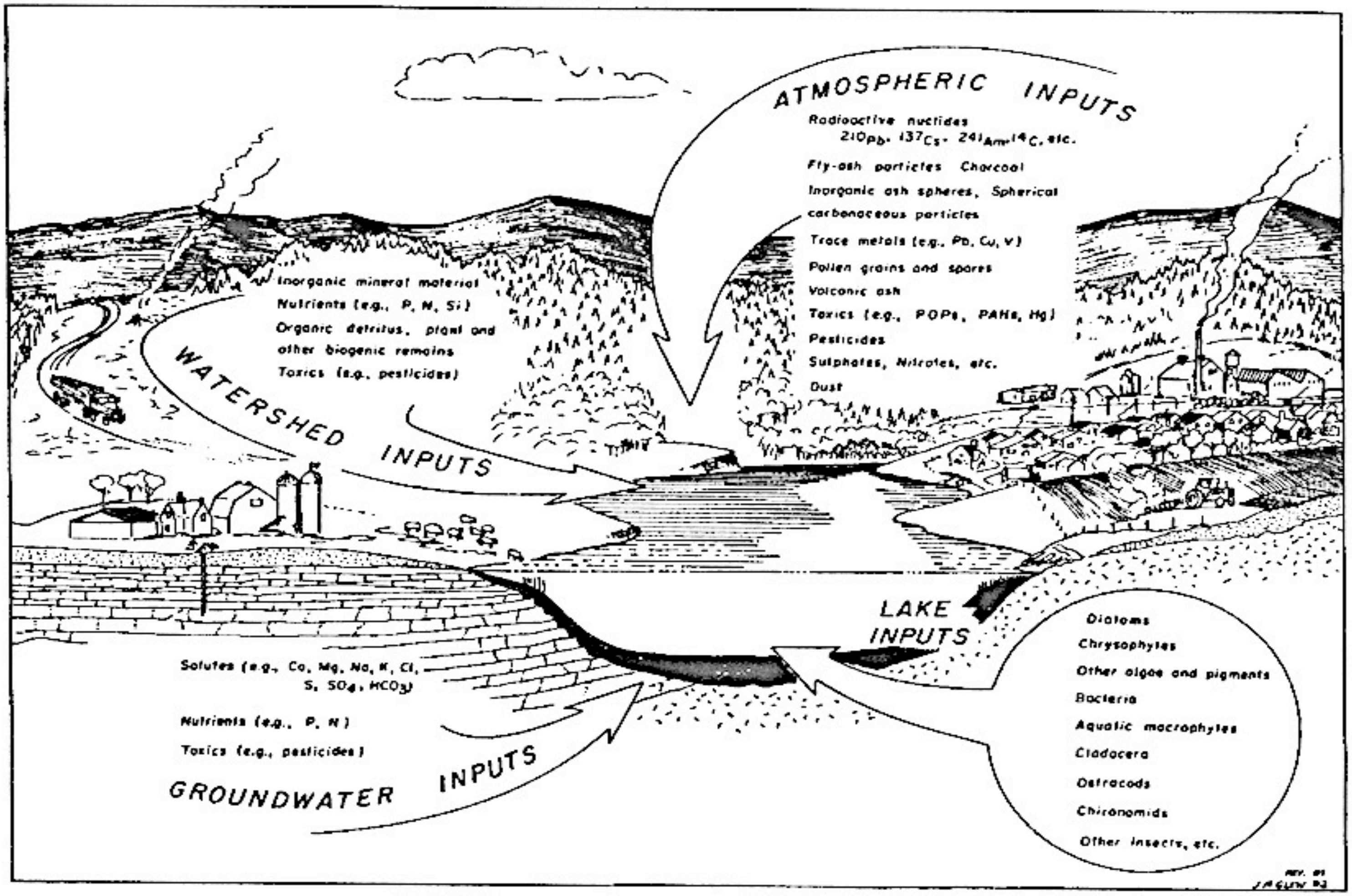

Figure 2.1 – Diagram showing allochthonous and autochthonous inputs and proxy indicators in a lake (Smol, et al., 2001).

2.2.1 Coring

To build an archive of the past, a sediment core must be collected first. For paleoecologists the collection of sediment cores requires multiple considerations to ensure the accuracy of results. In other disciplines errors can be adjusted or corrected after data collection, however in paleoecology this is not the case. The whole dataset and subsequent archive is dependent on the collection of a good sample. A good core sample is an undisturbed, unmixed and continuous sediment sample (Glew et al., 2001).

The characteristics of the lake sediments can vary in both density and consistency, which can determine the type of corer to use. A major factor is the shear strength required. Shallow sediments with high water content require low shear strength whereas deeper sediments can be well compacted or consolidated, requiring high shear strength. Generally, as depth increases, bulk density also increases. Another factor in determining what type of corer to use is the temporal range of the project. The length of the sediment core sets the temporal resolution of the archive and dataset (Smol et al., 2012). With a large variety of corers to choose from it is best to consider both the scope of the project and the characteristics of the sediment being collected.

The gravity corer is a common coring device that is often used as it is the least expensive, and simplest option (Glew et al., 2001). As the name suggests this corer uses gravity and the weight of the coring device to enter the sediment. The main advantage of a gravity corer is a quick and simple recovery of short sediment cores. Also, the core tubes are easily removed and the sediment can be extruded to subsample in the field. They provide a profile of recent lake sediment, even when water content is very high. Therefore, they are a great option when collecting a surficial core sample or a short core. The main disadvantage of some gravity corers is they can create turbulence in front of the tube, disturbing the sediment. This is called the bow wave effect (Glew et al., 2001). Disturbance can be avoided by using a messenger-operated gravity corer where the core tube is open until penetration is complete, and then the core is closed by the researcher from the surface by dropping a messenger along a line attached to the top of the corer. When the messenger strikes the top of the corer, it disengages a stopper that seals the core top and creates a vacuum that allows the sediments to be removed from the lake bottom. The only difficulty with this technique is it is more complex as the researcher has to be able to determine when the core has reached the bottom and penetrated the sediment. Another common coring device is a piston corer. This technique requires a stable platform and instead of using gravity the tube is driven manually into the sediment. Sediment is recovered once the corer has penetrated fully into the sediment and a piston creates the necessary suction to remove the sediment from the lake bottom. The advantage of this corer lies in the operation of the piston and the seal. The seal stops any displacement or disturbance of sediment even when sampling soft sediments and the piston allows for easy penetration of compact sediment with little force. The piston corer can collect over 10 metres of sediment in 1-metre sections, making it a suitable option for the collection of long sediment records. The main disadvantage of this technique is the corer is only applicable is relatively shallow waters, generally <30 meters (Glew et al., 2001). Once both the surficial and long cores are collected, proxies can be analysed, compared and matched between cores to create a continuous stratigraphic record.

2.2.2 Chronology

Developing a reliable chronology is a crucial component of paleoecological studies (Birks and Birks, 2006). Suitable calibration of a record's chronology will ensure an accurate dataset and corresponding inferences of lake and landscape conditions.

Occasionally, sediments will be varved or laminated, showing annual layers of sediment throughout the entire sequence. This allows for a high-resolution analyses and strong confidence in the accuracy of the chronology. By observing annual layers in sediment, a detailed record can be created dating back hundreds to over ten thousand years (Lamoureux, 2001). An absolute chronology can be created when the record is continuous, whereas cross-dating unique signatures from multiple samples or multiple sites can create a floating chronology. This cross-dating technique of linking multiple samples is similar to dendrochronological methods (Lamoureux, 2001).

Unfortunately, most sediment records do not contain annual varves. Instead, most sediment records are comprised of massive sediments with little to no visible structure. Given the lack of structure, a chronology in a sediment core comprised of massive sediments is normally developed using radiocarbon dating techniques. Radiometric dating relies on the radioactive decay of elements, including carbon-14 (^{14}C) and lead-210 (^{210}Pb). Isotopes of ^{14}C have a half-life of 5568 years (Björck and Wohlfarth, 2001). Based on this decay rate the age of fossil material can be determined. The half-life of ^{14}C means this technique can only be used back to approximately 60,000 years ago, however in the scope of paleoecology research this is normally a suitable range. Lake sediments often contain organic carbon in different forms throughout the sediment profile. These different forms can include plant, animal and terrestrial matter, making radiocarbon dating ideal for paleoecology. In the past conventional methods of ^{14}C dating required 0.5-1 gram of pure carbon for dating methods and in the case of samples with low carbon content this could be problematic leading to dating uncertainties and large standard errors. However, the more recent method of accelerator mass spectrometry (AMS) requires much less carbon (1-10mg) leading to better resolution and smaller errors. Therefore, AMS ^{14}C dating is the most commonly used method today (Björck and Wohlfarth, 2001 & Maher, Heiri and Lotter, 2012).

The most significant limitation of radiocarbon dating is that every date provided has a statistical uncertainty as a result of background radiation and measurement uncertainty. Therefore if a date was expressed as 3560±120 ^{14}C yr BP, the exact date could lie between a range of 3440-3680 yr BP, with 68% confidence. To increase the confidence to 95% the uncertainty increases by another standard deviation and the range becomes 3320-3800 yr BP (Björck and Wohlfarth, 2001). There are some statistical techniques to overcome this limitation. Once all the dates are obtained, an age-depth model is created and calibrated for this uncertainty. An age-depth curve is determined by different regression analysis techniques to find the curve that best fits the model with the least amount of uncertainty. This important step can vary from linear or polynomial interpolation to more advanced techniques. However, more recent statistical techniques, including Bayesian analysis, are now being employed. Another limitation is due to increased carbon dioxide content in the atmosphere from the burning of fossil fuels and from the testing of nuclear weapons. The burning of fossil fuels has altered the ^{14}C content by releasing older CO_2 into the atmosphere, whereas the testing of nuclear weapons has increased ^{14}C production (Björck and Wohlfarth, 2001). Therefore radiocarbon dating cannot be used for sediments deposited in the past ~150 years. This can be overcome by relying on other radioactive elements, such as ^{210}Pb. ^{210}Pb is an important dating technique that complements ^{14}C dating, as it can be used to date sediments deposited during the last 150 years, effectively filling the gap or limitation of

^{14}C (Appleby, 2001). ^{210}Pb is based on the natural decay of the radioactive isotope of lead, which has a half-life of 22.3 years. The two models commonly used in ^{210}Pb dating are the constant rate of supply (CRS) and constant initial concentration (CIC). The CRS model is commonly used with reliable results, when sedimentation rates are constant.

2.3 Fire History Reconstruction

The main proxies used in fire history reconstructions include charcoal, pollen, loss-on-ignition and magnetic susceptibility. These complementary analyses are used together to create a record of past fire activity. The following section will discuss these different proxies, important processes such as production and transportation as well as the importance of site selection.

2.3.1 Charcoal Production and Transport

Charcoal is one of the main proxy indicators used in fire reconstructions. Therefore, it is important to understand the processes of how charcoal is produced and deposited in lake sediment. Charcoal is produced when organic matter burns incompletely at temperatures ranging from 280°C to 500°C (Umbanhowar and Mcgrath, 1998). During the heating process the moisture from the fuel is first evaporated at temperatures > 100°C, then the cellulose breaks down thermally and is volatilized at temperatures > 200°C. Finally, a visible flame is formed at temperatures between 300-400°C (Johnson, 1992). Charcoal composition can vary with different temperatures. Lower temperatures produce larger particles due to less combustion (Pyne et al., 1996), while temperatures of 450°C or higher produce charcoal that is more brittle (Nichols et al., 2000). When temperatures exceed 500°C there is normally complete combustion of grass and leaf material, which creates a higher abundance of wood charcoal (Umbanhowar and Mcgrath, 1998).

Primary charcoal is charcoal that is deposited during or directly after a fire event. Secondary charcoal refers to the material that is deposited after the event during non-fire years, as a result of surface runoff and sediment mixing. It is important to note the distinction as both sources make up the sediment charcoal record, however in different ways (Figure 2.2). Primary charcoal is generally characterized as a large deposition of charcoal particles directly after a fire, while secondary charcoal is the smaller influx of charcoal that occurs during non-fire years and may persist for several years following a fire event. Therefore, the amount of charcoal that accumulates in lake sediment following a fire is a result of both the fire characteristics, such as fire size and intensity, as well as the processes that transport the charcoal to the lake (Whitlock and Larsen, 2001).

Charcoal morphology is an additional tool to better understand macroscopic charcoal transportation. Enache and Cumming (2004) suggest that fragile morphotypes can be useful in identifying fire events within the sedimentary record as they do not produce false-positive signals and can be useful for identifying fires that do not have a strong fire signal as a result of smaller charcoal peaks.

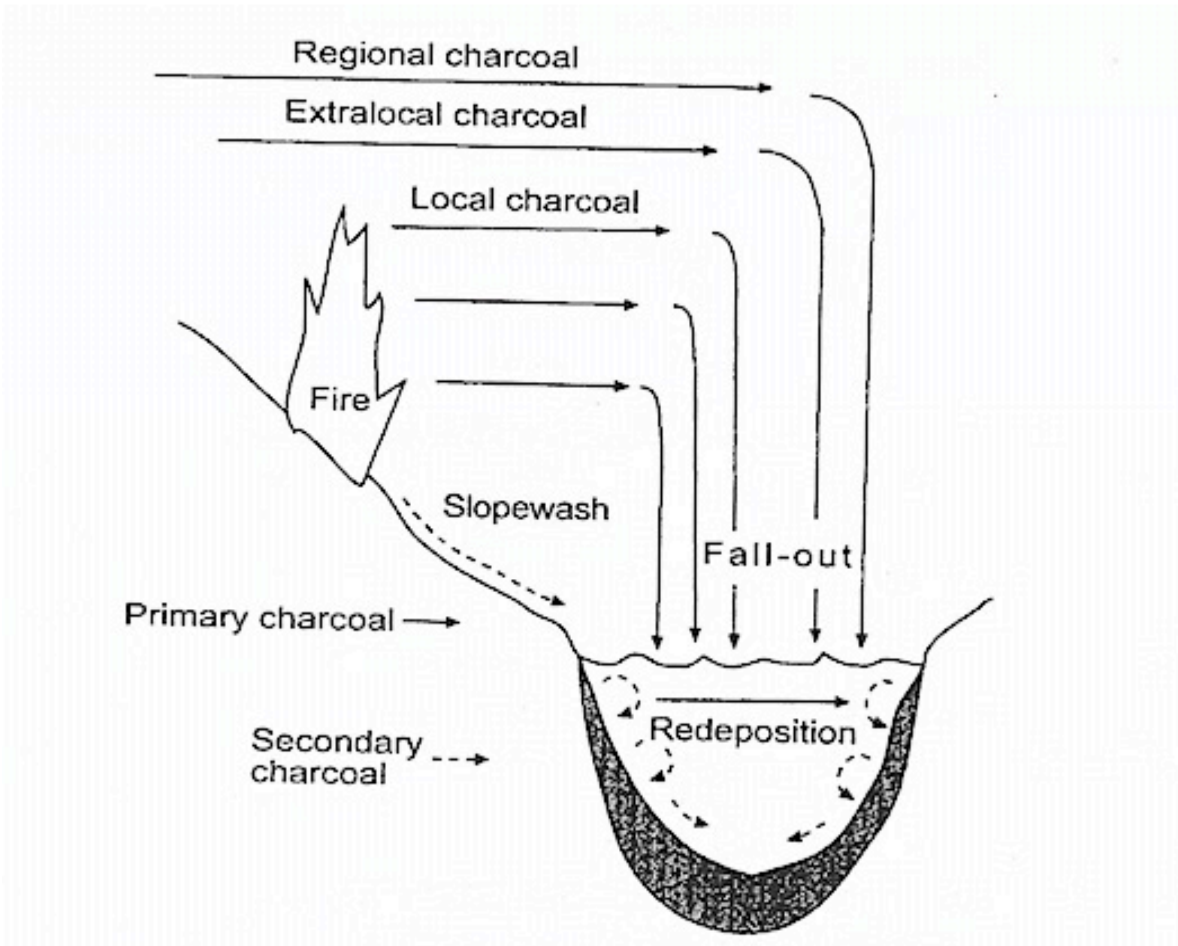

Figure 2.2 – Primary and secondary sources of charcoal in lake sediment records (Whitlock and Larsen, 2001).

Previous theoretical models (Clark, 1988) and empirical studies (Whitlock and Millspaugh, 1996) suggest that macroscopic charcoal particles (>125μm) are generally deposited close to a fire. These macroscopic particles are deposited <7 km, and are typically deposited within a few hundred metres of the fire. In contrast, microscopic charcoal particles (<125μm) can be carried great distances (Gardner and Whitlock, 2001). Therefore, the source of the charcoal in the sediment record may be from regional fires that were distant, extra-local fires that occurred nearby but not within the watershed of the lake, or local fires that did occur within the watershed. Macroscopic charcoal can accurately represent local fires, whereas microscopic charcoal provides information on regional fires, but cannot identify specific fire events. Gardner and Whitlock (2001) conducted a fire reconstruction in an area with known fire dates and results of their study indicate that a peak in macroscopic charcoal can be identified, which represents a specific local fire event. This validates the theory of charcoal fire reconstructions and the notion that macroscopic particles are generally not transported far from their source. Further, Gardner and Whitlock (2001) also concluded that the majority of macroscopic charcoal is deposited during or shortly after a fire. Therefore, peaks in a macroscopic charcoal record represent nearby fire events and thus macroscopic charcoal records can in fact be used to identify fire events in the past (Clark, 1988; Whitlock, and Millspaugh, 1996; Gardner and Whitlook, 2001; Whitlock and Larsen 2001; Higuera et al., 2010).

However, it is important to note that Pisaric (2002) suggests that intense forest fires can create convection and vortices that can carry macroscopic charcoal and other burned plant material over long distances and deposit them many kilometres away from a fire. These macroscopic remains can include conifer needles, cones and charcoal.

2.3.2 Site Selection

Site selection is important in paleoecology research as the characteristics of both the watershed and the lake can influence results. The processes discussed in the previous section on charcoal production and transport are important to understand for site selection as they affect how much charcoal will be present in the sediment record. When selecting a site to provide an accurate fire record, the aim should be to maximize primary charcoal and minimize the amount of secondary charcoal entering a lake (Whitlock and Larsen, 2001).

An important characteristic for site selection is the size of the watershed relative to lake size. A large watershed provides a greater source of charcoal, as charcoal from fires located within the watershed could potentially find its way into a lake. Therefore, larger watersheds relative to lake size can increase the allochthonous input. Whitlock and Millspaugh (1996) suggest that these sites have a greater amount of macroscopic charcoal following a fire. A large watershed to lake ratio can increase the detection and limnological signal of a fire event. However, this large ratio can also lead to the introduction of greater amounts of secondary charcoal as a result of the greater surface area and thus creating more background noise (Whitlock and Larsen, 2001).

Topography is an important factor to limit the amount of secondary charcoal in a record. Whitlock and Larsen (2001) suggest that steep slopes experience greater rates of erosion leading to more secondary charcoal entering the lake. A lack of inflowing streams that can transport secondary charcoal is also important for limiting the introduction of secondary charcoal in the record. Additionally, the presence of riparian vegetation along the shore of a lake can help trap some of this undesirable charcoal. Whitlock and Millspaugh (1996) suggest some additional characteristics to look for when choosing a study site, including a relatively deep lake in comparison to the surface area. This will help to limit the amount of sediment mixing through wind and wave action. In addition to water depth, simple bathymetry with a shallow littoral zone is important for consistent sedimentation rates. Whitlock and Millspaugh (1996) found that sampling from the deepest point of the lake is best because this area shows the most consistent charcoal accumulation rate. A recent study by Courtney Mustaphi et al. (2015) supports this. A final site characteristic that is important for paleofire reconstructions using lake sediment records is a record of known fire dates in the lake watershed. Known fire dates are critical to assist with core calibration and can also be used in validating radiocarbon and ^{210}Pb chronologies.

2.3.3 Charcoal Analysis

Macroscopic charcoal analysis can produce fire records on a decadal to millennial scale, and improve on the microscopic pollen-slide methods in terms of both spatial and temporal resolution (Schlachter and Horn, 2010). Macroscopic charcoal analysis is conducted by analyzing contiguous samples throughout a sediment core, normally varying from 0.25cm to 1cm intervals, which are then sieved through a 125μm sieve and the charcoal caught on the sieve is backwashed in to a petrie dish where the charcoal particles are counted under a microscope. Each subsample is soaked in a deflocculant solution of sodium hexametaphosphate as well as hydrogen peroxide overnight before they are gently washed through the sieves. This helps to disaggregate the sample and bleaches dark organic material that might be confused with macroscopic charcoal. In comparison to other charcoal analysis methods, the sieving technique is generally faster and less expensive (Whitlock and Larsen, 2001; Schlachter and Horn, 2010). Once the charcoal is counted, it is quantified as charcoal accumulation rates (CHAR). CHAR typically shows the slowly varying background noise from input of secondary charcoal during non-fire years, and the high frequency charcoal peaks that represent immediate deposition of charcoal during or shortly after a fire event. The statistical software programs used to create thresholds and CHAR datasets have advanced in recent years (Kelly et al., 2011). CHARAnalysis is a common software program used to detect peak charcoal counts, indicating local fire events. Peaks in macroscopic charcoal records are distinguishable from the slowly varying background noise and are thought to represent local or extra-local fire events. Peaks are differentiated from the background noise by applying a threshold function using statistical software programs like CHARAnalysis. Charcoal concentrations that exceed the background threshold represent peaks or fire events in the charcoal record, while charcoal concentrations that fall below the threshold represent the slowly varying background charcoal (Gardner and Whitlock, 2001; Whitlock and Larsen, 2001; Schlachter and Horn, 2010; Kelly et al., 2011).

2.3.4 Pollen

Pollen plays an integral role in the reproduction of plants, however much of the pollen produced by plants does not fulfill its reproductive purpose. Instead, these pollen grains fall on the land or water bodies. On land and exposed to an aerobic environment, the pollen grains decompose. Pollen that falls on the surface of water bodies and sink through the water column can eventually become incorporated into the sediment at the bottom of the lake. In this low-oxygen environment, pollen can become preserved in the sediment. Palynology is the scientific discipline that analyses pollen grains and other subfossils preserved in lake sediment for the purpose of reconstructing past environmental conditions.

The amount of pollen produced by a plant varies amongst species. Plant species that are anemophilous, or wind-pollinated, produce copious amounts of pollen. Those that are entomophilous (insect-pollinated) invest more heavily in showy flowers that attract their insect pollinators and thus produce less pollen. Thus, plants that disperse pollen via wind generally produce more pollen over a greater area. Pollen grains are microscopic, ranging from ~10μm to 100μm, depending on the species. Pollen grains are normally well preserved in lake sediment records because of the high content of sporopollenin. Sporopollenin is a chemically inert biological polymer that is extremely resistant to both chemical and physical degradation, but not oxidation (Bennett and Willis, 2001). This is significant in pollen analysis because:

1) Once deposited in lake sediment, pollen is preserved indefinitely as the sediment-water interface is often a low-oxygen environment.
2) Strong acids and bases can be used to remove most of the sediment matrix, leaving behind the pollen for analysis.

Pollen grains from different plant types have different shapes, sizes and ornamentation that differ between taxon and allow for identification of the pollen to genus and sometimes species level.

Stomata are subfossil plant remains that are analysed in combination with pollen analysis to provide information about vegetation history in a particular area. Stomata are guard cells that are found on the leaves or stems of a plant. These openings allow for oxygen, carbon dioxide and water to be exchanged between the atmosphere and the plant (MacDonald, 2001). Stomata contain high amounts of lignin. Like sporopollenin, lignin makes the stomata resistant to decay and aids in their preservation in lake sediment records. Given lignin is normally more abundant in conifer species compared to deciduous species, the stomata of conifers are often observed in lake sediment records. Because stomata are found on leaves, they are generally not transported great distances from their source. This differs compared to most types of pollen, which are easily dispersed in the atmosphere and can travel great distances. Therefore, identification of species from their stomata in lake sediment records can indicate what the local vegetation was in the past. Given the issue of long distance transport of many types of pollen, pollen analysis can provide information about past vegetation primarily at extra-local to regional scales.

Pollen analysis is often used in fire reconstructions to complement charcoal studies because subfossil pollen can be used to reconstruct past vegetation and its response to past environmental change (Bennett and Willis, 2001). Changes in the vegetation as a result of fire can sometimes be seen in pollen records. Some plant species are fire sensitive and have limited or no adaptations to cope with the impacts of fire. Therefore, peaks and troughs in the pollen record of fire adapted and fire sensitive species can be compared with the charcoal record from the same lake to confirm fire events (Whitlock and Larsen, 2001). Pitkänen and Huttunen (1999) show that spruce (*Picea)* is the most suitable pollen type to detect a local fire, where a temporary decline in *Picea* pollen indicates a fire. *Picea* pollen grains are large and heavy in comparison to pine (*Pinus*), and as a result approximately half of *Picea* pollen grains are deposited within 500 m of their source. Also spruce is very sensitive to fire, so even non-severe fires can kill all the spruce in an area. Therefore, a decline in *Picea* pollen following a peak in charcoal, can indicate a local fire. Pollen ratios are also used to detect past fire events in lake sediment records. Ratios of pollen from species that live in open environments that would be typical following a fire event versus species that are more common in a closed canopy forest can be computed. Many studies (Pitkänen and Huttunen, 1999; Davis et al., 2016) have used a *Picea-Pinus* ratio, as many *Pinus* species are fire tolerant or well adapted to fire. However, it is important to note the sedimentation rates have to be high enough to be able to detect rapid changes in vegetation.

Pollen analysis can also be useful to understand the slowly varying background noise in charcoal records, as this is a result of fuel characteristics and vegetation type (Whitlock and Larsen, 2001). For example, a region that is dominated by a mixed conifer forest will have abundant woody fuel, leading to higher background levels of charcoal. In contrast, an area with less woody fuels such as open parkland, will produce less background charcoal (Whitlock et al., 2003). Marlon et al. (2006) examined the relationship between background charcoal and vegetation by analyzing 15 charcoal and associated pollen records. Results suggest that charcoal abundance is a result of site characteristics, such as lake and watershed size, as well as proportion of woody taxa. The sedimentation rate and fire frequency had little influence on background charcoal levels. Marlon et al. (2006) found that as woody taxa increased throughout the Holocene so did the background charcoal levels. Therefore, background levels are influenced by fuel characteristics, which are a function of climate and vegetation type.

2.3.5 Lithology

Lithological variation in a sediment core can indicate a change in the environment and are used in fire reconstructions to complement charcoal analysis. Magnetic susceptibility and Loss-on-ignition (LOI) are often used to help detect fire signals. However, similar to secondary charcoal, these can sometimes be unrelated to a fire and instead represent other types of disturbances such as mass wasting events (Whitlock and Larsen, 2001).

Rummary et al. (1979) were the first to use mineral magnetism to detect fire events in sediment records. Gedye et al. (2000) show that the process of magnetic enhancement, which occurs in the topsoil during a fire, allows for the detection of a fire magnetically. This magnetic enhancement mainly occurs when temperatures exceed 500°C and is caused by iron minerals being converted into ferrimagnetic oxides in the presence of organic matter. Therefore, magnetic susceptibility can be used to detect changes in the mineral content of lake sediment (Sandgren and Snowball, 2001).

LOI is a widely used proxy in paleoecology and is a useful complement to charcoal analysis (Birks and Birks, 2006). LOI determines the amount of organic and calcium carbonate content in sediment (Dean, 1974). An inverse relationship may be present where charcoal, magnetic susceptibility and silicilastic content increases while organic content decreases. This may represent fire-induced processes occurring on the landscape, such as increased erosion post fire, however this is not always detectable in the lake sediment (MacDonald et al., 1991). Magnetic susceptibility, LOI, pollen and charcoal analysis form a complementary set of analyses that allow for a greater certainty in the detection of local to extra local fire events in sediment records.

2.4 Fire Behaviour

Wildfire is natural within the forest life cycle and is associated with both positive and negative impacts. This is especially true in the boreal forest where fire is the most prominent disturbance agent (Bergeron et al., 2001; Rowe and Scotter, 1973)

Three fire types have been identified; crown, ground and surface (DeBano et al., 1998; Natural Resources Canada, 2016; Whelan, 1995). Table 2.1 below summarizes the different fire types. Pausas (2015) suggests species that are considered fire tolerators have thicker bark and are more prone to understory type fires, such as ground and surface fires. Fire embracing species are prone to larger crown fires as many of them can efficiently regenerate following a burn. Current research shows that boreal forests in North America have evolved in association with fire and include a number of species that quickly re-grow and colonize after crown fires (Rogers et al., 2015). In Canada, the main species that rely on fire for renewal include jack pine (*Pinus banksiana*), lodgepole pine (*Pinus contorta*) and black spruce (*Picea mariana)*. These species rely on stand-replacing fires as a result of their serotinous cones that remain sealed until they are heated to about 50-60°C during a fire (Brandt et al., 2013; NRC, 2015; Rogers et al., 2015).

The common fire triangle describes the conditions needed for fire ignition and includes oxygen, an ignition source and fuel (Whitlock et al., 2010). Other fire triangles also describe the necessary conditions and characteristics of wildfires at increasing spatial and temporal scales, such as fire events and a fire regime (Figure 2.3). A fire event is controlled by weather, fuel and local controls, while the fire regime is controlled by vegetation, climate and landscape controls.

Table 2.1 – Description of different fire types, their impact on ecosystems and their spatial characteristics.

Fire Type	Crown	Surface	Ground
Size	Large	Small	Small
Impact	Most dangerous, causing the largest amount of damage	Small, causing the least amount of damage	Small, causing little damage
Description	Full sized fire; stand replacing	Litter and debris accumulates on forest floor and burns; easiest to manage	Layer of humus and dead vegetation; slow burn and can be difficult to extinguish

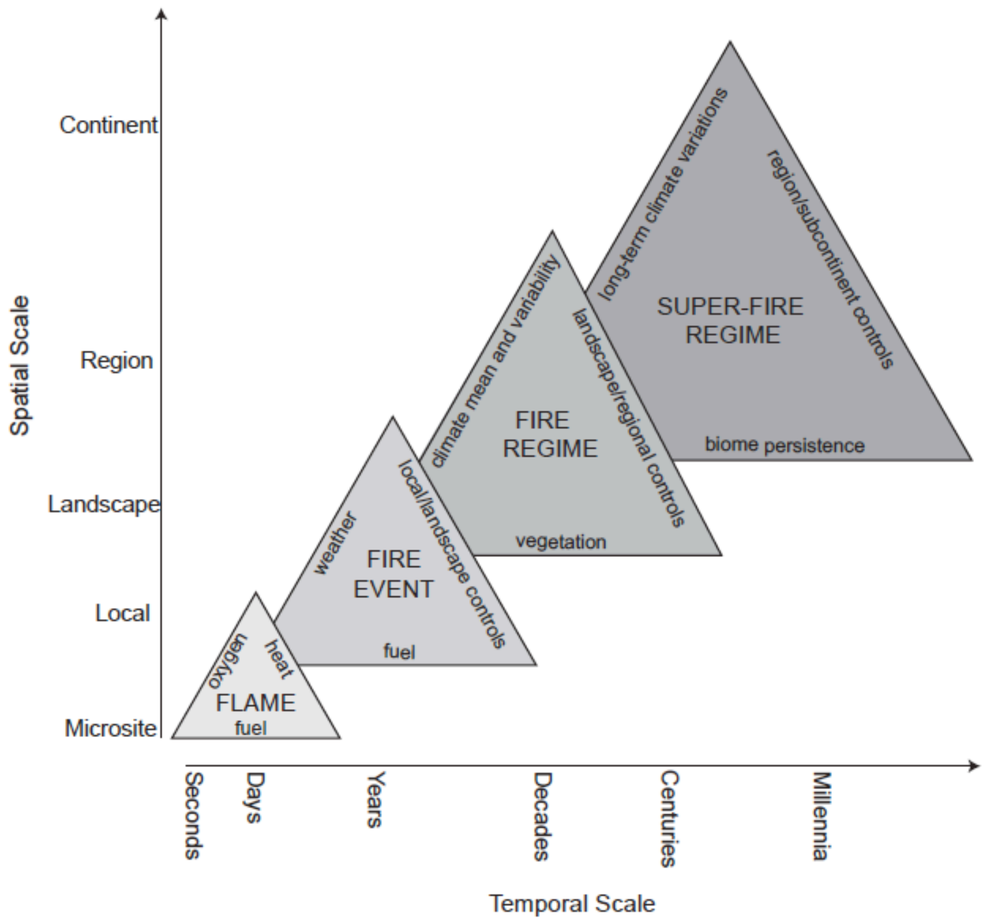

Figure 2.3 – Fire triangle at different spatial and temporal scales (Whitlock et al., 2010).

2.4.1 Weather and Fuel

Fuel loads are important for fire as they control fire type and intensity and are often influenced by short-term weather patterns. Of the factors that can influence fire in the boreal forest, weather and climate are the two most important (Flannigan and Wotton, 2001). Short-term weather patterns affect fuel moisture, as well as controlling the spread of fire (Liu and Wimberly, 2015). Meanwhile, the long-term climate affects species distribution in the area, essentially influencing fuel load. These weather and climate influences are known as top-down controls.

These top-down controls include temperature, precipitation, humidity, wind, and weather systems (Liu and Wimberly, 2015; Flannigan and Wotton, 2001; DeBano et al., 1998 and Whelan, 1995). High temperatures can contribute to the drying of fuels through increased evaporation. When temperature increases the flammability increases as well since the fuels dry out faster and more extensively. Precipitation is a very important controlling factor, along with relative humidity. Prolonged periods of little to no precipitation with low relative humidity can rapidly dry out fine fuels, increasing the likelihood of ignition and spread of fire (Whelan, 1995). Wind is another important aspect as high winds can dry out fine fuels, increase oxygen supply and can even preheat or ignite fine fuels ahead of the fire front. Therefore, fires spread rapidly during periods of hot, dry and windy conditions (Flannigan and Wotton, 2001). Flannigan and Harrington (1988) studied fires across Canada and found that the severe fire months were unrelated solely to total rainfall amounts. Instead they were often dependent on rainfall frequency, temperature and relative humidity, suggesting an important relationship between all factors.

These different controls can affect two of the three components of the fire triangle, fuel and oxygen, but they can also affect the third component, ignition. Although humans are responsible for a large number of fires, whether they are intentional or unintentional, lightning is a significant cause of fire as well (NRC, 2016). Lightning is responsible for just under 50% of fires in Canada (NRC, 2016). However, in the boreal forest lightning is responsible for the majority of the area burned and lightning ignitions have been increasing since 1975 (Veraverbeke et al., 2017). Convective storms that bring unstable conditions are often accompanied by lightning, providing the necessary ignition source, especially following periods of hot and dry conditions (Flannigan and Wotton, 2001).

Weather systems are an important control of fire because they dictate atmospheric conditions, such as temperature, precipitation and wind for several days to a week. Atmospheric pressure patterns are also important in controlling the frequency and severity of wildfires over periods of days to weeks. Areas under the influence of atmospheric ridges are dominated by stagnant, high-pressure systems which can persist for weeks to months (Daley, 1991) and bring warm and dry conditions. Over these extended periods, fine fuels can dry out leading to ideal conditions for fire ignition and spread. When these ridges breakdown they often create increased lightning activity, as a result of the atmospheric disturbance. Accompanying the lightning are strong, gusty surface winds, which enhance fire spread. Therefore, these ridges dry out fuel sources, increase combustion due to strong winds and generate ignitions in the form of lightning, effectively completing the fire triangle. Nimchuk (1983) identified two of these upper atmospheric ridges that lead to severe burning in Alberta, Canada. These systems lasted for 8 days and lead to approximately 1,000,000 hectares of burned land.

2.4.2 Local Factors and Topography

Local site factors such as topography and vegetation are considered bottom-up controls of fire (Courtney Mustaphi and Pisaric, 2013) and can have a significant influence on fire activity; in some cases a stronger influence than climate (Liu and Wimberly, 2015). These bottom up controls can affect fire size, severity and occurrence.

Topography creates different microclimates within a larger climate zone, and can influence the fuel load and supply, as well as indirectly affect the vegetation type. Topographical features such as mountain ranges can create varying microclimates where some areas receive more precipitation and some areas receive less. Microclimates with less precipitation will have fuel loads that are more susceptible to fire. However, they can also provide natural firebreaks as well. Mountainous regions, large river systems, and lakes can act as fire breaks where fire can no longer continue to burn due to the lack of fuel continuity (Courtney Mustaphi and Pisaric, 2014; Whelan, 1995). Slope also plays an important role as fire burns faster upslope and slower downslope. When burning upslope the convective heat preheats and dries the fuel ahead of it, which does not occur when a fire burns downslope (Whelan, 1995). The final topographic influence is aspect. Different slopes will receive varying amounts of sunlight during the day, with south-southeast facing slopes receiving the most amount of sunlight. Therefore, south-southeast facing slopes will have fuels that are drier and warmer, potentially ignite more readily, and burn faster and more intensely. In a study by Gavin et al. (2006) a fire reconstruction was performed for two separate study sites and they attributed higher fire frequency at the one site to topography. The site with higher frequency had steep south-southwest facing slopes. Courtney Mustaphi and Pisaric (2013) also determined that aspect was an important bottom up control, where they concluded that fires were more frequent on south-facing slopes.

Vegetation is an important bottom-up control since it represents fuel loads and flammability. Courtney Mustaphi and Pisaric (2014) suggest that during the early Holocene in southern British Columbia, when conditions were dry and warm, the *Pinus* dominated forests were characterized by frequent fires. However, a cooler climate during the mid-Holocene led to Engelmann spruce-subalpine fir dominated forests and the fire regime became more variable with the change in vegetation.

2.4.3 Major Climatic Influences

Large-scale atmospheric patterns such as the El-Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) can also influence fire regimes and account for some of the multi-year to multidecadal variation in fire patterns (Kitzberger et al., 2007; Mjelde et al., 2007). These atmospheric patterns can alter both precipitation and temperature trends across North America and can often bring drought-like conditions to some areas, which are favourable for wildfire. Diaz et al. (2001) suggest that ENSO is the most important source of climate variability after the seasonal cycle.

ENSO is the warm phase of the Walker circulation where there is a reversal of the equatorial trade winds and an increase in sea-surface temperatures (SST) in the eastern equatorial Pacific Ocean (Rasmusson and Carpenter, 1982). PDO is a similar ocean-atmospheric pattern occurring at interdecadal scales and leads to variability in SST in the northern Pacific Ocean (Mantua and Hare, 2002). During the warm or positive phase the east Pacific warms while the west Pacific cools. Both PDO and ENSO have similar impacts that vary regionally and even globally, however these warm events are associated with long periods of warm and dry weather for western North America. During these phases stationary and blocking ridges of high pressure reduce precipitation leading to the drying of fuel (Kizberger et al, 2007). ENSO and PDO have often been linked to an increase in fire activity and severity. Kitzberger et al. (2007) found that both ENSO and PDO were the main drivers for high frequency variation in fire over western North America. Kitzberger et al. (2007) also suggest that these large-scale ocean-atmosphere patterns can be useful guides for potential fire hazards.

Low-pressure systems coming from the northeast Pacific bring frequent storm activity. Meanwhile high-pressure in the summer months are associated with clear conditions and warm temperatures. The Aleutian Low (AL) (Figure 2.4) is a semi-permanent low-pressure system that can impact the climate in Yukon (Spooner et al., 2003; Anderson et al., 2005). The AL strengthens and weakens as it oscillates between an eastern and western Pacific position. The eastern position brings warm, moist air over coastal regions of western North America. However, strong southwesterly winds and the rain shadow effect from the St. Elias Mountains limits precipitation in central Yukon. When the AL moves west, zonal flow is established, allowing for more precipitation to be funneled into the interior of Yukon. Therefore, a strong AL (positioned to the east) is often associated with low precipitation and dry conditions that are more amenable to increased fire activity. Conversely, a weak AL (positioned further to the west) is often associated with zonal flow patterns and increased precipitation in the interior of Yukon.

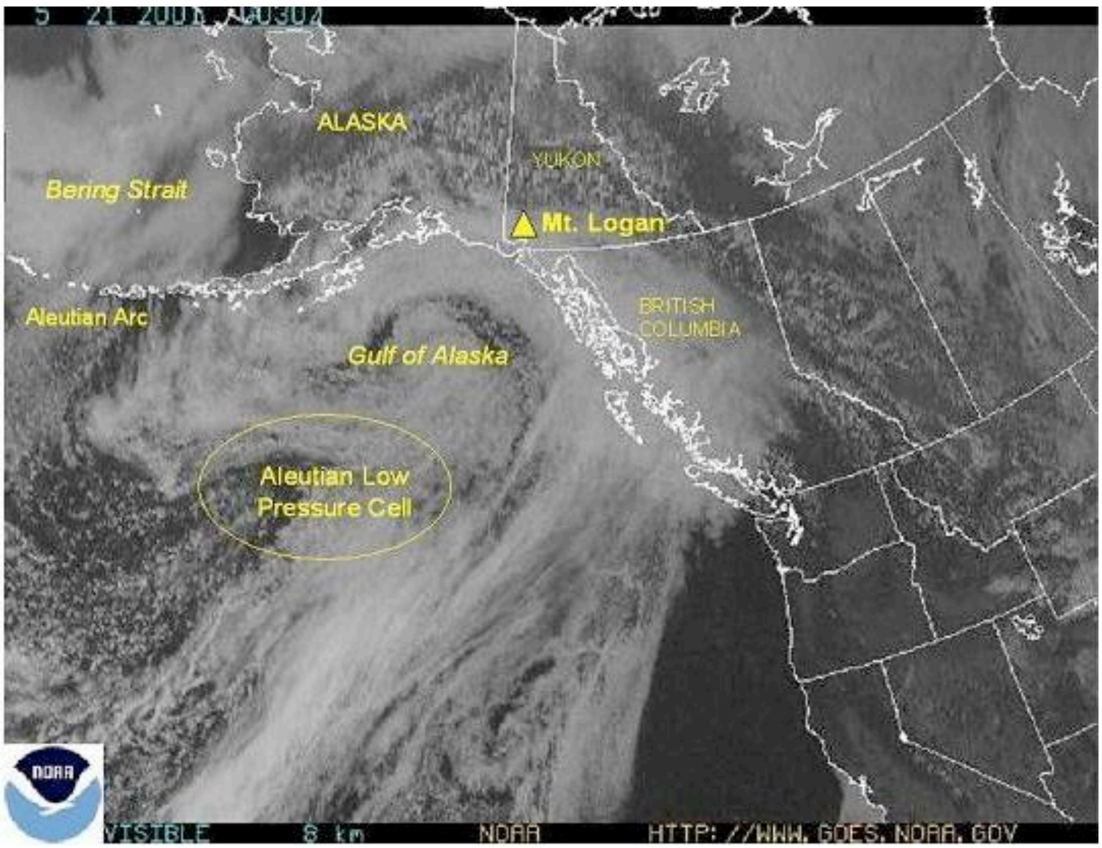

Figure 2.4 – Strong and easterly positioned Aleutian Low pressure system originating over the North Pacific Ocean. This image shows the precipitation being carried up the coastline by the strong south-southwest winds (NOAA, 2001).

2.5 Climate Change and Wildfire

It is now clear that the climate is changing due to the anthropogenic production of greenhouse gases. Concentrations of greenhouse gases such as carbon dioxide and methane are now exceeding atmospheric concentrations during any period in the past 800,000 years (EPICA, 2004). As the concentration of greenhouse gases continues to rise, global mean surface temperatures have also increased. However, temperature is not experiencing a uniform increase. For example, the Arctic is warming at rates greater than the global average (ACIA, 2008). Over the past few decades Arctic temperatures have been increasing at twice the global rate, with surface air temperatures 1°C above the 20th century average in the past decade (ACIA, 2004).The Intergovernmental Panel on Climate Change (IPCC) suggests the period 1983-2012 was likely the warmest 30-year period in the past 1400 years (IPCC, 2014). Conditions follow the same trend in Yukon, where average annual temperatures have increased by 2°C over the last 50 years, with more warming projected in the coming years (Streicker, 2016). Precipitation has also increased in Yukon by 6% over the last 50 years, however it is quite variable both temporally and spatially. According to Natural Resources Canada (2016) one of the impacts of rising global mean temperatures will be larger, more severe fires resulting in more area burned. Flannigan et al. (2009) suggests that fire activity is closely linked to weather and an increase in fire activity as a result of climate change is expected or arguably has already occurred. McCoy and Burn (2005) support this, suggesting that although fire will vary annually, overall the frequency and extent of fire may increase in central Yukon. As climate change continues it is expected that alterations in fire regimes will also occur.

Fire regimes are complex as they have many different drivers that can affect fire, therefore climate change can directly influence fire by increasing the probability of a fire, or indirectly by changing the vegetation type and the flammability of the landscape (Higuera et al., 2014). A recent study by Flannigan et al. (2013) used three GCMs with different emission levels to project future fire severity and season length, using 1971-2000 as a baseline period. Their results showed that in all scenarios and models there were significant increases in fire severity and fire season length, with the greatest increases projected for the Northern Hemisphere at the end of the 21st century. Flannigan et al. (2013) suggest that an increase in fire frequency and severity will make current fire management practices ineffective, as the increasing burden will exceed budgets and available resources. McCoy and Burn (2005) conducted a modeling exercise specifically for central Yukon. They found that the average annual area burned may double by 2069 and the maximum number of fires may increase by two-thirds over current values. In addition, Flannigan et al. (2009) suggest that there may be a net warming effect from boreal fires as a positive feedback loop may occur due to increasing fire activity. A warmer, drier climate that is more conducive to fires will have positive feedback implications on the global climate system. More fires will increase carbon releases to the atmosphere, which in turn will enhance climate warming.

The effects of climate change are already happening with record fire years occurring in the past decade. In 2015, over 4 million ha burned across the United States, which exceeds the previous record set in 2006 and is ~1.6 million ha above average (National Interagency Fire Center, 2015). Since 2000, nine of the ten worst years in terms of area burned have occurred and 2015 was the worst fire year on record in the US as a result of severe drought conditions that were likely exacerbated by climate change (USDA, 2015). In Canada, a similar story has developed in recent decades. British Columbia has exceeded their budget for fighting wildfires four of the five years, from 2010 to 2014, (Province of British Columbia, 2015) and in 2015 Saskatchewan had to evacuate over 13,000 people in the La Ronge area due to a fire event, as a result of a prolonged period with a lack of precipitation and high temperatures (CIFFC, 2015). Currently, the 2017 wildfire season in British Columbia is no better. The British Columbia Wildfire Service (2017) reported it has experienced the worst wildfire season on record. As of August 16th, 2017 ~900,000 ha have burned, already surpassing the previous record of 855,000 ha burned in 1958, and $315.7 million has been spent on fighting the fires.

Currently, Canada spends approximately $500 million annually on fire suppression; as fire activity increases this costs will likely rise as well. Prior to 2004 Yukon had an annual budget of $13 million. However, after the 2004 fire year, when total suppression costs reached $22.1 million, a provision was adding for a contingency budget of $30 million (Yukon Wildland Fire Management, 2005). With the current increase in fire activity, Flannigan et al. (2009) suggest that conditions already overwhelm fire suppression efforts when they become extreme, leading to significant losses in property and land. These large, high intensity, less controllable fires that are >200 ha in size only make up 3% of all fires, however they are responsible for approximately 97% of the area burned (Stocks et al. 2003). With future climate warming leading to more of these large fires, our current management strategies will be compromised in the coming decades, requiring a reassessment and change in approach (Flannigan et al., 2009).

2.6 Wildfire in Yukon

A number of paleoenvironmental studies focusing on climate and environmental change during the late Pleistocene and Holocene have been conducted in Yukon in recent decades (Yalcin et al., 2006; Anderson et al., 2007; Gajewski et al., 2014; Edwards et al., 2015). However, many of these studies have not been done at high temporal resolution with well-dated sequences (Gajewski et al., 2014). Also, there are few paleo-fire studies that have reported a full record throughout the Holocene. For example, Yalcin et al. (2006) provided a 1000-year fire record for southern Yukon from the Mount Logan ice core. Recently, Edwards et al. (2015) examined the role of fire in Yukon throughout the Holocene. However, this study was primarily focused on the effects of fire on vegetation, specifically lodgepole pine, as opposed to the overall fire regime in Yukon. Also, fire reconstructions are a local representation of fire activity. Therefore, multiple reconstructions in a region are required to produce the spatial scale necessary for strong paleo-fire records over broad regions. This lack of high-resolution fire records in Yukon has been identified as a gap in the research (Gajewski et al., 2014).

Southwest Yukon is located in the boreal forest biome, which according to La Roi (1967), is relatively uniform and low-diversity in terms of tree species. The circumpolar boreal forest is the largest forest ecosystem on the planet and comprises approximately 27 million hectares of land in Yukon (Yukon Wildland Fire Management, 2005). Similar to other boreal zones around the globe, this area has both environmental and economic significance; in 2013 the forest sector contributed $19.8 billion or 1.25% to Canada's gross domestic product (GDP; NRC, 2016).

The four main conifers that occur in the central to southwestern Yukon are white spruce (*Picea glauca),* black spruce (*Picea mariana*), tamarack (*Larix laricina*) and lodgepole pine. Common hardwoods include Alaska birch (*Betula neoalaskana*) and trembling aspen (*Populus tremuloides*) with understory shrubs of green alder (*Alnus crispa*), willow (*Salix*) and dwarf birch (*Betula nana*; Edwards et al., 2015). As previously mentioned, vegetation has an important relationship with fire. Black spruce and lodgepole pine have semi-serotinous and serotinous cones, respectively, that release and disperse seeds when heated by fire. Lodgepole pine commonly experiences and survives low-intensity ground fires, which can eliminate competition from understory species. However, large crown fires are also common in lodgepole pine-dominated forests when drought conditions are present or there is a build-up of fuel supply (Bourgeau-Chavez et al., 2000). Both pine and black spruce tend to establish dominance after a fire due to their ability to release seeds immediately following a fire, whereas white spruce rely on survivor trees to recolonize a burned area (Edwards et al., 2015). Hardwood species can distribute their seeds across a larger area and will opportunistically invade after a fire. Also, some species use suckers to reproduce asexually after fire.

The boreal forests of Yukon are often subjected to large stand-replacing fires (Yukon Wildland Fire Management, 2005), resulting in a patch-work mosaic of forest stands of differing age-classes in different successional stages. Hogg and Wein (2005) found that mixedwood forests dominated by white spruce are slow to regenerate post fire, resulting in uneven-aged stages where the vegetation may resemble that of an aspen parkland. The growth of both spruce and aspen is strongly related to precipitation, therefore these forests are vulnerable if climate becomes drier under future change. Recent studies by Johnstone and Chapin (2006) and Johnstone et al. (2010) indicate that recent fire activity in Yukon is altering vegetation assemblages and changing the balance in some forest ecosystems from conifer-dominated systems to forests dominated by deciduous species. Such changes will lead to feedbacks in these systems as fuel loads and flammability of those fuels change.

Lightning accounts for approximately 55% of fires started in Yukon, while the other remaining 45% are a result of human activity (Yukon Wildland Fire Management, 2005). The human caused fires tend to be smaller in nature, while the lightning caused fires are responsible for the larger stand-replacing fires, resulting in a large area burned. In the past 25 years Yukon has experienced an average of 140 fires, burning 120 000 ha of land every year (Yukon Wildland Fire Management, 2005). However, similar to other boreal forests, fire in the Yukon has annual variability with cycles of higher fire activity and years with lower frequencies. Significant fire activity occurred in 2004, when a total of 282 fires accounted for over 1.7 million hectares of burnt land. In response, the Government of Yukon struck an independent review panel, named the Wildland Fire Review Panel, to evaluate the 2004 fire year in relation to the historical fire regime, assess Yukon's approach to fire management and to assess the impacts these fires had at a community and governmental level. The panel (Yukon Wildland Fire Management, 2005) found that fires in 2004 were a result of unprecedented temperatures, a lack of rainfall for a long period, and unusual lightning storms. Fire management was deemed a success, as there was no loss of life and minimal property loss.

While very few fire studies exist for Yukon, Yalcin et al. (2006) performed a study where they reconstructed a 1000-year fire record from an ice core recovered from the Eclipse Icefield in southwest Yukon. Results from their study showed that there was increased fire activity in this area during the period from 1240 to 1410 AD. This period coincides with the Medieval Climate Anomaly, which has varying dates in the range of 900 to 1300 AD. Therefore, this increased fire activity may have been a result of warmer and drier conditions brought on by the Medieval Warm Period. It is important to note that the Medieval Warm Period was not a global phenomenon; some areas in fact remained cool during this period, which is why it is now often referred to as the Medieval Climate Anomaly (MCA) (Yalcin et al., 2006 & Young et al., 2005).

Figure 2.5 shows the current extent of the documented fire history throughout Yukon Territory from 1946 to 2015. This map also shows the geographic extent of the different eco-zones in the Yukon. There are several recent fires within the Southern Lakes watershed, which are based on remotely sensed spatial data from the Government of Yukon. The fire year and size can be seen in Table 2.2. Multiple fires occurred in 1948, 1958 and 1998, with the largest fire in 1958 burning 126,903 ha of land.

The Yukon Wildland Fire Management is currently responsible for managing and suppressing fires in Yukon. With only 23 crews placed throughout the Territory, it is a small organization that is responsible for managing a vast area of land. They are mainly an initial attack organization, who respond quickly while the fire is still small, however the organization does have prevention, pre-suppression and suppression protocols in place (Yukon Wildland Fire Management, 2005). The FireSmart program is considered a successful program and a model for other Canadian jurisdictions. This program offers funding for communities, municipal governments, First Nations and school communities to help better understand fire ecology and improve responsibility in preventing human-caused fires. Fire prevention advice includes reducing fuel sources from the yard such as branches, needles and brush. In 2014 alone, $830,000 was spent on reducing fuel loads by thinning trees and clearing brush in communities (Yukon Department of Environment, 2015). Although the Yukon Wildland Fire Management (2005) deemed the FireSmart program effective, Hennessey and Streicker (2011) considered its effectiveness as limited. An additional prevention method has been implemented by the Forest Management Branch where they have reduced fuel loads in 105 hectares of forest in southwest Yukon since 2009 (Yukon Department of Environment, 2012). Pre-suppression efforts include the use of MODIS satellite imagery by the Yukon Wildland Fire Management to detect fire (Yukon Wildland Fire Management, 2005). In addition, an analysis of historic fire risk and a daily calculation of fire danger levels are used to increase preparedness in Yukon. However, improvement areas that were identified include pre-positioning initial attack crews to reduce response time and increase coverage, as well as improving initial attack times by reducing get-a-way times. In addition to the 23 firefighting crews, suppression efforts rely on air operations that include air tankers and helicopters. The helicopters are hired when needed and help improve the initial attack effort as well as transport crews. Lastly, the Wildland Fire Management uses their resources efficiently by implementing a 5-zone system. The response zones make up 25% of the Territory, where human values take priority over natural values. The critical fire management zone (Zone 1) prioritizes high value areas, such as communities, where the aim is for complete fire control and suppression. In contrast the wilderness fire management zone (Zone 5) allows fires to burn in remote areas, taking advantage of the natural ecological benefits of wildfire. This zoning policy allows for timely suppression, limiting the losses within the response zones.

Table 2.2 – Fires Occurring within the Southern Lakes ecoregion from 1946-2015.

Fire Year	Fire Size (Hectares)
1947	425
1948	763
1948	32
1948	19
1951	333
1958	281
1958	126,093
1960	725
1991	1000
1998	10,364
1998	30
2003	799

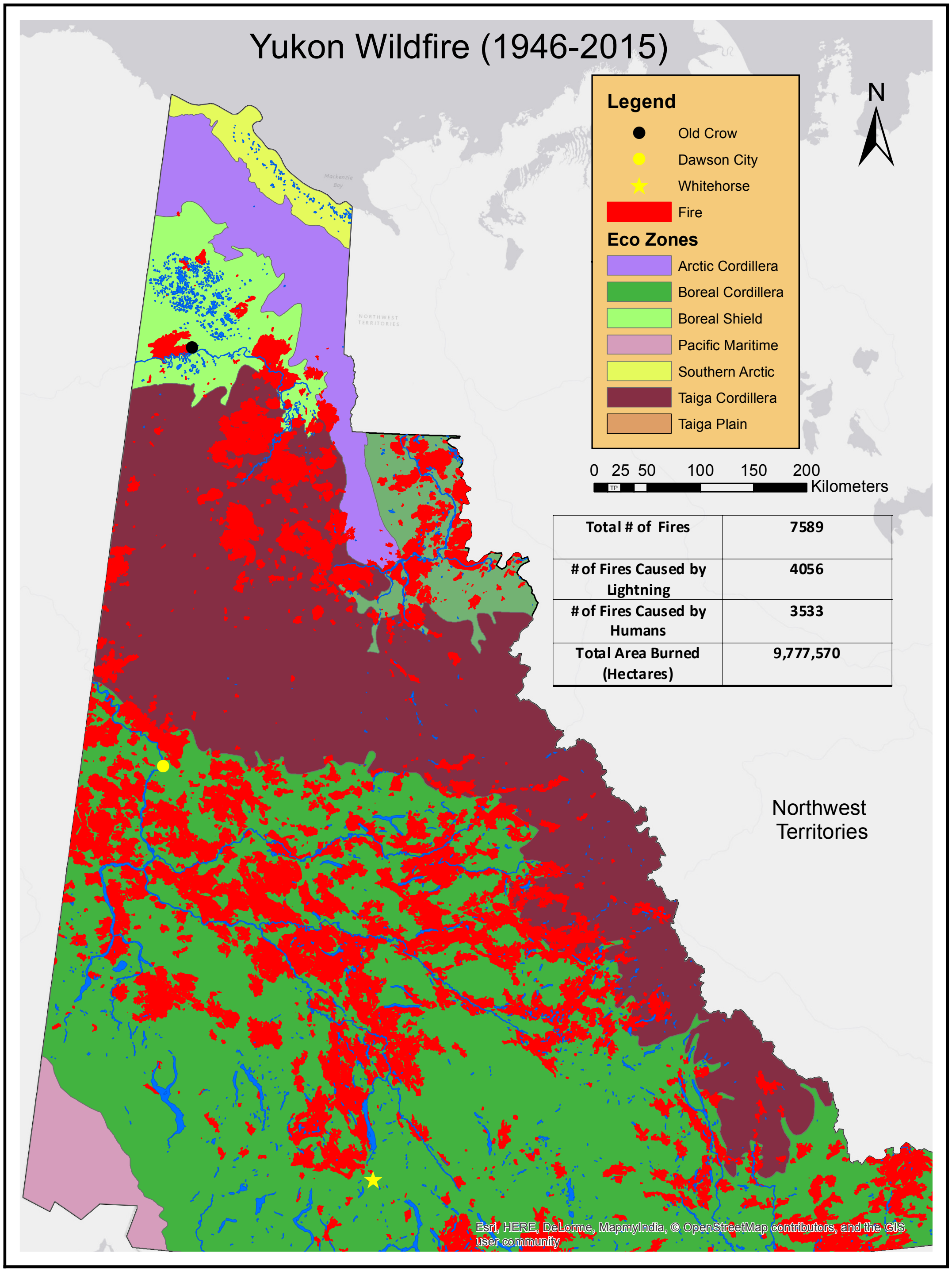

Figure 2.5 – Map showing the spatial distribution of wildfire in Yukon from 1946 – 2015. This also shows the extent of the different ecozones throughout Yukon (Government of Yukon, 2016).

REFERENCES

Anderson, L., Abbott, M. B., Finney, B. P., & Burns, S. J. (2005). Regional atmospheric circulation change in the North Pacific during the Holocene inferred from lacustrine carbonate oxygen isotopes, Yukon Territory, Canada. *Quaternary Research*, 64(1), 21-35.

Anderson, L., Abbott, M. B., Finney, B. P., & Burns, S. J. (2007). Late Holocene moisture balance variability in the southwest Yukon Territory, Canada. *Quaternary Science Reviews*, 26(1), 130-141.

Appleby, P.G. (2001). Chronostratigraphic Techniques in Recent Sediments. In W.M. Last & J.P. Smol (eds.), 2001. *Tracking Environmental Change Using Lake Sediments. Volume 1: Basin Analysis, Coring and Chronological Techniques.* Dordrect: Kluwer Academic Publishers, 2001, pp. 171-203.

Assessment, A. C. I. (2004). Impacts of a Warming Arctic-Arctic Climate Impact Assessment. *Impacts of a Warming Arctic-Arctic Climate Impact Assessment, by Arctic Climate Impact Assessment, pp. 144. ISBN 0521617782. Cambridge, UK: Cambridge University Press, December 2004.*, 144.

B.C. Wildfire Service. (2017). *Current Statistics.* Retrieved from http://bcfireinfo.for.gov.bc.ca/hprScripts/WildfireNews/Statistics.asp

Bennett, K. D., & Willis, K. J. (2001). Pollen. In J.P. Smol, H.J.B. Birks & W. M. Last (eds.), 2001. *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators.* Dordrecht: Kluwer Academic Publishers, 2001, pp. 5-32.

Bergeron, Y., Gauthier, S., Kafka, V., Lefort, P., & Lesieur, D. (2001). Natural fire frequency for the eastern Canadian boreal forest: consequences for sustainable forestry. *Canadian Journal of Forest Research*, *31*(3), 384-391.

Birks H.H. & Birks H.J.B. (2006). Multi-proxy studies in palaeolimnology. *Vegetation History and Archaebotany*, 15, 235–251.

Björck, S., & Wohlfarth, B. (2001). ^{14}C Chronostratigrahic Techniques in Paleolimnology. In W.M. Last & J.P. Smol (eds.), 2001. *Tracking Environmental Change Using Lake Sediments. Volume 1: Basin Analysis, Coring and Chronological Techniques.* Dordrect: Kluwer Academic Publishers, 2001, pp. 205-245.

Bourgeau-Chavez, L. L., Alexander, M. E., Stocks, B. J., & Kasischke, E. S. (2000). Distribution of forest ecosystems and the role of fire in the North American boreal region. *Fire, climate change, and carbon cycling in the boreal forest*, 111-131.

Brandt, J., Flannigan, M., Maynard, D., Thompson, I., & Volney, W. (2013). An introduction to Canada's boreal zone: ecosystem processes, health, sustainability, and environmental issues. *Environmental Reviews*, *21*(4), 207-226.

Clark, J. S. (1988). Particle motion and the theory of charcoal analysis: Source area, transport, deposition, and sampling. *Quaternary Research*, *30*67-80

Canadian Interagency Forest Fire Center. (2015*). Canadian Interagency Forest Fire Centre Inc.National Wildland Fire Situation Report.* Retrieved from http://www.ciffc.ca/firewire/current.php?lang=en&date=20150710

Cohen, A. S. (2003). *Paleolimnology: the history and evolution of lake systems*. Oxford : New York : Oxford University Press, c2003.

Courtney Mustaphi, C. J., & Pisaric, M. F. (2013). Varying influence of climate and aspect as controls of montane forest fire regimes during the late Holocene, south-eastern British Columbia, Canada. *Journal of Biogeography*, *40*(10), 1983-1996.

Daley, R. (1991). *Atmospheric Data Analysis*. Cambridge University Press, Cambridge.

Davis, E. L., Mustaphi, C. J. C., Gall, A., Pisaric, M. F., Vermaire, J. C., & Moser, K. A. (2016). Determinants of fire activity during the last 3500 yr at a wildland–urban interface, Alberta, Canada. *Quaternary Research*, *86*(3), 247-259.

DeBano, L.F., Neary, D.G., & Ffolliott, P.F. (1998). *Fire's Effects on Ecosystems.* John Wiley & Sons.

Dean, W.E. (1974). Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss-on-ignition: comparison with other methods. *J Sedimentary Petrol, 44:*242–248

Diaz, H. F., Hoerling, M. P., & Eischeid, J. K. (2001). ENSO variability, teleconnections and climate change. *International Journal of Climatology*, *21*(15), 1845-1862.

Edwards, M., Franklin-Smith, L., Clarke, C., Baker, J., Hill, S., & Gallagher, K. (2015). The role of fire in the mid-Holocene arrival and expansion of lodgepole pine (Pinus contorta var. latifolia Engelm. ex S. Watson) in Yukon, Canada. *Holocene*, *25*(1), 64-78.

Enache, M. D., & Cumming, B. F. (2006). Tracking recorded fires using charcoal morphology from the sedimentary sequence of Prosser Lake, British Columbia (Canada). *Quaternary Research*, *65*(2), 282-292.

EPICA Community Members. (2004). Eight glacial cycles from an Antarctic ice core. *Nature 429*, 623-628.

Flannigan, M., Cantin, A. S., de Groot, W. J., Wotton, M., Newbery, A., & Gowman, L. M. (2013). Global wildland fire season severity in the 21st century. *Forest Ecology and Management*, *294*, 54-61.

Flannigan, M. D., and Harrington, J. B. (1988). A study of the relation of meteorological variables to monthly provincial area burned by wildfire in Canada 1953-80. *Journal of Applied Meteorology.* 27, 441-452.

Flannigan, M. D., Logan, K. A., Amiro, B. D., Skinner, W. R., & Stocks, B. J. (2005). Future area burned in Canada. *Climatic change*, 72(1), 1-16.

Flannigan, M., Stocks, B., Turetsky, M., & Wotton, M. (2009). Impacts of climate change on fire activity and fire management in the circumboreal forest. *Global Change Biology*, 15(3), 549-560.

Flannigan, M.D., and Wotton, B.M. (2001). Climate, weather and area burned. In Forest fires: behavior and ecological effects. Edited by E.A. Johnson and K. Miyanishi. Academic Press, San Diego, California. pp. 335–357.

Gardner, J., & Whitlock, C. (2001). Charcoal accumulation following a recent fire in the Cascade Range, northwestern USA, and its relevance for fire-history studies. *Holocene*, *11*(5), 541-549.

Gavin, D. G., Hu, F. S., Lertzman, K., & Corbett, P. (2006). Weak climatic control of stand-scale fire history during the late Holocene. *Ecology*, *87*(7), 1722-1732.

Gajewski, K., Bunbury, J., Vetter, M., Kroeker, N., & Khan, A. H. (2014). Paleoenvironmental studies in southwestern Yukon. *Arctic*, *67, Suppl. 1*58-70.

Gedye, S., Jones, R., Tinner, W., Ammann, B., & Oldfield, F. (2000). The use of mineral magnetism in the reconstruction of fire history: a case study from Lago di Origlio, Swiss Alps. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *164*(Fire and the Palaeoenvironment), 101-110.

Glew, J.R., Smol, J.P., & Last, W.M. (2001). Sediment Core Collection and Extrustion. In W.M. Last & J.P. Smol (eds.), 2001. *Tracking Environmental Change Using Lake Sediments. Volume 1: Basin Analysis, Coring and Chronological Techniques.* Dordrect: Kluwer Academic Publishers, 2001, pp. 73-105.

Government of Canada. (2017). *Historical Climate Data.* Retrieved from http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=1617&autofwd=1

Heiri, O., Lotter, A., & Lemcke, G. (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal Of Paleolimnology*, *25*(1), 101-110.

Hennessey, R. and Streicker, J., 2011. Whitehorse Climate Change Adaptation Plan. *Northern Climate ExChange, Yukon Research Centre, Yukon College, Whitehorse, YT*.

Higuera, P.E., C.E. Briles, and C. Whitlock. (2014). Fire-regime complacency and sensitivity to centennial- through millennial-scale climate change in Rocky Mountain subalpine forests, Colorado, U.S.A. *Journal of Ecology*. 102: 1429-1441.

Higuera, P. E., Gavin, D. G., Bartlein, P. J., & Hallett, D. J. (2010). Peak detection in sediment–charcoal records: impacts of alternative data analysis methods on fire-history interpretations. *International Journal of Wildland Fire*, 19(8), 996-1014.

Higuera, P.E., D.G. Gavin, P.D. Henne, and R.F. Kelly. (2010). Recent advances in the analysis and interpretation of sediment-charcoal records. *PAGES Newsletter,18: 57-59.*

Hogg, E. H., & Wein, R. W. (2005). Impacts of drought on forest growth and regeneration following fire in southwestern Yukon, Canada. *Canadian Journal of Forest Research*, *35*(9), 2141-2150.

IPCC, 2014: Summary for Policymakers, *In: Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer,O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B.Kriemann, J. Savolainen, S. Schl.mer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Johnson, J.A. (1992). *Fire and Vegetation Dynamics: Studies from the North American boreal forest*. New York: Cambridge University Press.

Johnstone, J. F., & Chapin, F. S. (2006). Fire interval effects on successional trajectory in boreal forests of northwest Canada. *Ecosystems*, 9(2), 268-277.

Johnstone, J. F., McIntire, E. J., Pedersen, E. J., King, G., & Pisaric, M. J. (2010). A sensitive slope: estimating landscape patterns of forest resilience in a changing climate. Ecosphere, 1(6), 1-21.

Kelly, R.F., P.E. Higuera, C.M. Barrett, and F.S. Hu. (2011). A signal-to-noise index to quantify the potential for peak detection in sediment-charcoal records. *Quaternary Research, 75: 11-17.*

Kitzberger, T., Brown, P. M., Heyerdahl, E. K., Swetnam, T. W., & Veblen, T. T. (2007). Contingent Pacific–Atlantic Ocean influence on multicentury wildfire synchrony over western North America. *Proceedings of the National Academy of Sciences*, *104*(2), 543-548.

Lamoureux, S. (2001). Varve Chronology Techniques. In J.P. Smol, H.J.B. Birks & W. M. Last (eds.), 2001. *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators.* Dordrecht: Kluwer Academic Publishers, 2001, pp. 1-3.

La Roi, G. H. (1967). Ecological studies in the boreal spruce-fir forests of the North American taiga. I. Analysis of the vascular flora. *Ecological Monographs*, 37(3), 229-253.

Liu, Z., & Wimberly, M. C. (2015). Climatic and Landscape Influences on Fire Regimes from 1984 to 2010 in the Western United States. *Plos ONE*, *10*(10), 1-20.

MacDonald, G. M. (2001). Conifer Stomata. In J.P. Smol, H.J.B. Birks & W. M. Last (eds.), 2001. *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators.* Dordrecht: Kluwer Academic Publishers, 2001, pp. 33-47.

MacDonald, G. (2003). Biogeography: Introduction to Space. Time and Life. Wiley, New York.

MacDonald, G. M., Larsen, C. P., Szeicz, J. M., & Moser, K. A. (1991). The reconstruction of boreal forest fire history from lake sediments: a comparison of charcoal, pollen, sedimentological, and geochemical indices. *Quaternary Science Reviews*, *10*(1), 53-71.

Maher, L.J., Heiri, O., & Lotter, A.F. (2012). Assessment of Uncertainties Associated with Palaeolimnological Laboratory Methods and Microfossil Analysis. In Birks, H. B. (2012). *Tracking Environmental Change Using Lake Sediments. [electronic resource]*. Dordrecht: Springer, 2012, pp. 143-166.

Mantua, N. J., & Hare, S. R. (2002). The Pacific decadal oscillation. *Journal of oceanography,* 58(1), 35-44.

Marlon, J., Bartlein, P. J., & Whitlock, C. (2006). Fire–fuel–climate linkages in the northwestern USA during the Holocene. *Holocene*, 16(8), 1059-1071.

McCoy, V. M., & Burn, C. R. (2005). Potential alteration by climate change of the forest-fire regime in the boreal forest of central Yukon Territory. *Arctic*, 276-285.

Mjelde, J. W., Litzenberg, K. K., Hoyle, J. E., Holochwost, S. R., & Funkhouser, S. (2007). Fires, Floods, and Hurricanes: Is ENSO to Blame?. *Science Scope*, *30*(7), 38-42.

Mustaphi, C. J. C., Davis, E. L., Perreault, J. T., & Pisaric, M. F. (2015). Spatial variability of recent macroscopic charcoal deposition in a small montane lake and implications for reconstruction of watershed-scale fire regimes. *Journal of Paleolimnology*, 54(1), 71-86.

Mustaphi, C. C., & Pisaric, M. F. (2014). Holocene climate-fire-vegetation interactions at a subalpine watershed in southeastern British Columbia, Canada. *Quaternary Research*, (2), 228-239.

National Interagency Fire Center. (2015). *Suppression Costs (1985-2015).* Retrieved from https://www.nifc.gov/fireInfo/fireInfo_documents/SuppCosts.pdf

National Oceanic and Atmospheric Administration. (2001). *Alaska Infrared: GOES West.* Retrieved from http://www.goes.noaa.gov/ak1.html

Natural Resources Canada. (2016). *Boreal Forest*. Retrieved from https://www.nrcan.gc.ca/forests/boreal/13071

Nichols, G. J., Cripps, J. A., Collinson, M. E., & Scott, A. C. (2000). Experiments in waterlogging and sedimentology of charcoal: results and implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *164*(1), 43-56.

Nimchuk, N. (1983). Wildfire Behavior Associated with Upper Ridge Breakdown. ENR Rep. No. T/50. Alberta Energy and Natural Resources, Forestry Service, Edmonton.

Patterson, R. T., Crann, C. A., Cutts, J. A., Courtney Mustaphi, C. J., Nasser, N. A., Macumber, A. L., & ... Falck, H. (2017). New occurrences of the White River Ash (east lobe) in Subarctic Canada and utility for estimating freshwater reservoir effect in lake sediment archives. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *477*1-9.

Pausas, J. G. (2015). Evolutionary fire ecology: lessons learned from pines. *Trends In Plant Science*, (5), 318-325.

Pitkänen, A., & Huttunen, P. (1999). A 1300-year forest-fire history at a site in eastern Finland based on charcoal and pollen records in laminated lake sediment. *Holocene*, *9*(3), 311-320.

Pisaric, M. (2002). Long-distance transport of terrestrial plant material by convection resulting from forest fires. *Journal Of Paleolimnology*, *28*(3), 349-354.

Province of British Colombia. (2015). *2015 Wildfire Season Summary.* Retrieved from http://bcwildfire.ca/History/Summary.htm

Pyne, S.J., Andrews, P.L., & Laven, R.D. (1996). *Introduction to Wildland Fire*. New York: John Wiley & Sons.

Ramsey, C. B. (2009). Bayesian analysis of radiocarbon dates. *Radiocarbon*, *51*(1), 337-360.

Rasmusson, E. M., & Carpenter, T. H. (1982). Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. *Monthly Weather Review*, *110*(5), 354-384.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Ramsey, C. B., ... & Grootes, P. M. (2013). IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon*, *55*(4), 1869-1887.

Rogers, B., Soja, A., Goulden, M., & Randerson, J. (2015). Influence of tree species on continental differences in boreal fires and climate feedbacks. *Nature Geoscience, 8*(3), 228-234.

Rowe, J. S., & Scotter, G. W. (1973). Fire in the boreal forest. *Quaternary research*, *3*(3), 444-464.

Rull, V. (2010). Ecology and palaeoecology: two approaches, one objective. *The Open Ecology Journal*, 3, 1-5.

Rummery, T.A., Bloemendal, J., Dearing, J.A., Oldfield, F., Thompson, R., 1979. The persistence of fire-induced magnetic oxides in soils and lake sediments. Annal. Geophysical. 35, 103–107.

Sandgren, P. & Snowball, I. (2001). Application of Mineral Magnetic Techniques to Paleolimnology. In W.M. Last and J.P. Smol (eds), 2001. *Tracking Environmental Change Using Lake Sediments. Volume 2: Physical and Geochemical Methods.* Dordrecht: Kluwer Academic Publishers, 2001, pp. 217-237.

Schlachter, K. J., & Horn, S. P. (2010). Sample preparation methods and replicability in macroscopic charcoal analysis. *Journal Of Paleolimnology*, (2), 701.

Smol, J.P., Birks, H.J.B., & Last, W.M. (2001). Using Biology to Study Long-Term Environmental Change. In J.P. Smol, H.J.B. Birks & W. M. Last (eds.), 2001. *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial,* *Algal, and Siliceous Indicators.* Dordrecht: Kluwer Academic Publishers, 2001, pp. 1-3.

Smol, J.P., Birks, H.J.B., Lotter, A.F., & Juggins, S. (2012). The March Towards The Quantitative Analysis of Paleolimnological Data. In Birks, H. B. (2012). *Tracking Environmental Change Using Lake Sediments. [electronic resource]*. Dordrecht: Springer, 2012, pp. 3-17.

Speer, J. H. (2010). *Fundamentals of tree-ring research*. University of Arizona Press.

Spooner, I. S., Barnes, S., Baltzer, K. B., Raeside, R., Osborn, G. D., & Mazzucchi, D. (2003). The impact of air mass circulation dynamics on Late Holocene paleoclimate in northwestern North America. *Quaternary International,* 108(1), 77-83.

Stocks, B. J., Mason, J. A., Todd, J. B., Bosch, E. M., Wotton, B. M., Amiro, B. D., Flannigan, M.D., Hirsch, K.G., Logan, K.A., Martell, D.L., & Skinner, W. R. (2003). Large forest fires in Canada, 1959-1997. *Journal of Geophysical Research, 108*(D1), FFR5-1.

Streicker, J. (2016). Yukon climate change indicators and key findings 2015. *Northern Climate ExChange, Yukon Research Centre, Yukon College*.

United States Department of Agriculture. (2015). *U.S. Forest Service.* Retrieved from http://www.fs.fed.us/news/releases/forest-service-chief-sets-expectations-agencys-efforts-during-2015-wildfire-season

Umbanhowar, C. E., & Mcgrath, M. J. (1998). Experimental production and analysis of microscopic charcoal from wood, leaves and grasses. *The Holocene*, *8*(3), 341-346.

Veraverbeke, S., Rogers, B. M., Goulden, M. L., Jandt, R. R., Miller, C. E., Wiggins, E. B., & Randerson, J. T. (2017). Lightning as a major driver of recent large fire years in North American boreal forests. *Nature Climate Change, 7(7*), 529-534.

Whelan, R. J. (1995). *The ecology of fire*. Cambridge University Press.

Whitlock, C & Larsen, C. (2001) Charcoal as a Fire Proxy. In J.P. Smol, H.J.B. Birks & W. M. Last (eds.), 2001. *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators.* Dordrecht: Kluwer Academic Publishers, 2001, pp. 75-97.

Whitlock, C., & Millspaugh, S. (1996). Testing the assumptions of fire history studies: An examination of modern charcoal accumulation in Yellowstone National Park, USA. *Holocene*, *6*(1), 7-15.

Whitlock, C., P.E. Higuera, D. McWethy, and C.E. Briles. (2010). Paleoecological perspectives on fire ecology: revisiting the fire regime concept. The Open Ecology Journal, 3: 6-23.

Whitlock, C., Shafer, S. L., & Marlon, J. (2003). The role of climate and vegetation change in shaping past and future fire regimes in the northwestern US and the implications for ecosystem management. *Forest ecology and management*, 178(1), 5-21.

Yalcin, K., Wake, C. P., Kreutz, K. J., & Whitlow, S. I. (2006). A 1000-yr record of forest fire activity from Eclipse Icefield, Yukon, Canada. *Holocene*, *16*(2), 200-209.

Young, N. E., Schweinsberg, A. D., Briner, J. P., & Schaefer, J. M. (2015). Glacier maxima in Baffin Bay during the Medieval Warm Period coeval with Norse settlement. *Science Advances*, *1*(11).

Yukon Department of Environment. (2012). *Yukon government climate change action plan progress report*. Whitehorse, YT: Government of Yukon.

Yukon Department of Environment. (2015). *Yukon government climate change action plan progress report*. Whitehorse, YT: Government of Yukon.

Yukon Wildland Fire Management. (2005). *2004 Wildland Fire Review: Final Report.* Whitehorse: Yukon Wildland Fire Management.

CHAPTER THREE

POSTGLACIAL RECONSTRUCTION OF FIRE HISTORY USING SEDIMENTARY CHARCOAL AND POLLEN FROM A SMALL LAKE IN SOUTHWEST YUKON, CANADA

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A modified version of this chapter will be submitted for publication in The Holocene.

1.1 Introduction

The circumpolar boreal forest is the largest forest ecosystem on the globe, comprising 17% of the earth's terrestrial surface (Stocks, 2004). The boreal forest is immensely valuable, both economically and as part of the global carbon cycle, storing as much as 30% of global terrestrial carbon.

Fire is one of the most prominent disturbance factors in the boreal forest (Johnson, 1992; Payette, 1992), shaping the forest in terms of age, composition and diversity (Weber and Stocks, 1998). Recent studies by Johnstone and Chapin (2006) and Johnstone et al. (2010) indicate that recent fire activity in Yukon is altering vegetation assemblages and changing the balance in some forest ecosystems from conifer-dominated systems to forests dominated by deciduous species. Such changes will lead to feedbacks in these systems as fuel loads and flammability of those fuels change.

Fire models suggest that the frequency and severity of forest fires across the boreal biome will likely increase during the current century as global temperatures continue to rise (Flannigan et al., 2005; Flannigan et al., 2009; Spracklen et al., 2009; IPCC, 2014). In the Yukon specifically, temperatures have increased 2°C over the last 50 years, with an additional increase of 2°C projected over the next 50 years (Streicker, 2016). In addition to the rising temperatures, other changes in climate are also being observed. Lightning ignitions represent the majority of the area burned in the boreal forest and lightning ignitions have been increasing since 1975 (Veraverbeke et al., 2017). Veraverbeke et al., (2017) found that a record number of lightning ignitions coincided with increased fire activity in the Northwest Territories in 2014 and Alaska in 2015. Similarly, the large fire year of 2004 in Yukon was attributed to unusual lightning activity (Yukon Wildland Fire Management, 2005). Additional information about the long-term occurrence of wildfire across the boreal biome is needed to refine predictions and improve planning and management of these forests during a period of rapid climatic and environmental change.

Wildfire has an important role in shaping the boreal ecosystem throughout Yukon in northwest Canada, however records of past fire occurrence and severity are geographically sparse and temporally short. Records of past wildfire occurrence in Yukon extend back to AD 1946 (Weber and Stocks, 1998), therefore it is difficult to assess natural fire regimes and develop management policies based on these temporally-short wildfire records when fire return intervals in the boreal forest typically range from 50 to >400 years (Bourgeau-Chavez et al., 2000: MacDonald, 2003 & Stocks, 2004). Although archived fire data is lacking in Yukon, fire reconstruction studies using macroscopic charcoal found in lake sediments can extend the temporal coverage of past wildfire activity. Lakes are ideal reservoirs of ecological information as they often persist on the landscape for millennia and accumulate material from both the terrestrial and aquatic environments (Smol, 2009). However, there have been few paleolimnological studies focused on past wildfire activity in Yukon that have been undertaken at high temporal-resolution in combination with well-dated sequences (Gajewski et al., 2014). Detailed analyses are needed to elucidate whether the frequency of wildfire and the range of natural variability are changing as the global climate system continues to warm.

Here, we reconstruct fire history from a small kettle lake in southwest Yukon. More specifically, we aim to identify the natural range of variability of the frequency of fire in this region as well as associated drivers. Results of this study will (1) establish the long-term fire history for the area in terms of total number of fires during the Holocene; (2) determine the mean fire return interval (mFRI); (3) determine if vegetation change, such as the arrival of lodgepole pine (*Pinus contorta*), altered fire frequency in the past; and (4) examine the major climatic drivers of fire in the area and their impact on fire regimes. Results of this research will provide forest managers with a detailed, long-term record of past wildfire activity for southwest Yukon, which will be useful to help assess risk more accurately as well as for fire modeling and prediction.

1.2 Study Site

1.2.1. Physical Environment

Spindly Pine Lake (unofficial name) is a small kettle lake with a maximum depth of at least 8 m and a surface area of 0.66 ha. The lake is located ~60 km south of Whitehorse, Yukon (60°18'6.03"N, 134°59'40.33"W; 787 m a.s.l.). Spindly Pine Lake lies in the recently-glaciated area of the southwest Yukon (Scudder, 1997) and was formed as a result of retreating glaciers from the Cordilleran ice sheet. The lake is a closed basin (Fig.1), lacking both inflowing and outflowing streams and is thermally stratified during the summer months (Fig. 2).

1.2.2. Climate

Spindly Pine is located within the southern lakes ecoregion of the Boreal Cordillera ecozone. The arid climate of this ecoregion is controlled by the rain shadow of the St. Elias coastal mountains (Smith et al., 2004), which create a dry and cool climate. Precipitation typically ranges from 200 to 325 mm per year, with ~30 to 50 percent occurring in the summer. Snow can fall at anytime during the year, but snow cover generally persists from late October until mid-April. The average annual temperature is -2°C. Winters are cold with average January temperatures of -21°C and summers are short and cool (average July temperature of 12-14°C) (Smith et al., 2004). However, the past few years (2012 – 2016) have been warmer with an average annual temperature of 1.1°C (Government of Canada, 2017).

Atmospheric pressure systems typically move across Yukon from west to east. The Aleutian Low pressure system (AL) impacts climate in Yukon as it oscillates between an eastern and western position (Trenberth and Hurrell, 1994; Spooner et al., 2003; Anderson et al., 2005). When the AL intensifies, it shifts to the east bringing warm, moist air over the coastal regions of western North America in a meridional pattern (Mock et al., 1998). The strong southerly winds associated with the AL pressure system move up the coast bringing intense precipitation for these coastal areas. However, due to the rain shadow effect of the St. Elias Mountains, the interior of Yukon experiences dry conditions with limited precipitation. When the AL weakens, the area of low-pressure shifts to the west over the north Pacific Ocean and a zonal flow pattern develops. This zonal flow pattern brings moist air across the mountain barriers and into the interior Yukon (Anderson et al., 2005). Therefore, a strong AL positioned over the eastern north

Pacific Ocean is often associated with low precipitation and dry conditions in southern Yukon, while a weak AL positioned over the western north Pacific Ocean is associated with a zonal flow pattern and increased precipitation in the interior of Yukon.

1.2.3. Glacial history and geologic setting

The Yukon Southern Lakes ecoregion is overlain with glacial till, glaciofluvial gravels and glaciolacustrine clay and silt deposits from the McConnell glaciation (Smith et al., 2004). The McConnell glaciation covered this region between 26 000 and 10 000 years ago (Jackson et al., 1991). The bedrock in the area is mainly coarse-grained metaphoric and granitic rock. Dominant soils are alkaline eutric brunisols, and are typically sandy and well drained. In exposed cutbanks throughout southern Yukon, a 2-5 cm thick layer of tephra is often visible (Smith et al., 2004). This tephra is the White River Ash (WRA) from Mount Churchill and was deposited ~1170 years BP (Davies et al., 2016).

1.2.4. Vegetation

The main conifers growing in this region include white spruce (*Picea glauca*), black spruce (*Picea mariana*), lodgepole pine (*Pinus contorta*) and subalpine fir (*Abies lasiocarpa)* at higher elevations (Smith et al., 2004). Lodgepole pine is the dominant tree species as it regenerates quickly after fire. Common hardwoods include Alaska birch (*Betula neoalaskana*) and trembling aspen (*Populus tremuloides*) with understory shrubs of alder (*Alnus crispa*), willow (*Salix*) and birch (*Betula nana*). Spindly Pine Lake is primarily surrounded by lodgepole pine, with white spruce also being abundant around the lake. Black spruce is absent. A stand of aspen also occurred on a steeper south-facing slope of the lake close to the water. (Fig. 1c).

1.3 Methodology

A continuous sediment record from the sediment-water interface down to 5.4-m below the sediment water interface was collected from Spindly Pine Lake. Sediment cores were collected from the lake centre (Courtney Mustaphi et al., 2015). The watery surface sediments were collected undisturbed using a Glew gravity coring system with internal diameter of 7.6-cm (Glew et al., 2001). Deeper sediments were collected using a modified Livingstone piston core with an internal diameter of 5 cm (Wright et al., 1984). The surface core was collected in August 2016 and the piston core in April 2006. Piston cores were extruded horizontally in the field, wrapped in cellophane and aluminum foil and shipped to the Brock University Water and Environmental Sciences Laboratory where they were stored at ~ 4°C until they were analysed. The surficial sediment core measured 48 cm in length and was subsampled in the field at 0.5-cm intervals.

The timing of the last fire around Spindly Pine Lake was estimated based on the age of trees within the catchment. Tree cores were collected in August 2016 from 1 white spruce and 21 lodgepole pine trees surrounding the lake. Cores were collected with a Haglof increment borer with an internal diameter of 4.3-mm. The samples were collected just above the root collar to ensure an accurate date of establishment for each tree. A total of 22 trees were sampled and aged using standard dendrochronological techniques (Speer, 2010). Cores were mounted on wood holders, sanded with progressively finer grit sandpapers and visually cross dated. Dated samples were grouped into 5-year bins to determine the timing of the most recent stand establishing fire.

1.3.1 Laboratory Methods

Piston cores were split lengthwise and sub-sampled at contiguous 0.5-cm intervals. Suitable samples for radiocarbon dating (macrofossils and bulk sediment) were removed and sent to the A.E. Lalonde AMS Laboratory at the University of Ottawa, Ottawa, Canada for ^{14}C dating using accelerator mass spectrometry (AMS). Ten ^{14}C dates, calibrated using IntCal13 (Reimer et al., 2013) and the White River ash deposit, were utilized to develop the age-depth model using the R Studio package Bacon V 2.2 (Blaauw and Christen, 2013). For depths throughout the core that were lacking macrofossils suitable for dating, bulk sediment samples were used instead. However, bulk sediment can often provide incorrect age estimates due to the freshwater reservoir effect (Patterson et al., 2017). To account for old carbon offsets associated with these samples, a bulk sediment sample was dated directly after the WRA to determine the offset between the bulk sediment age and the known age of the WRA deposit. The calculated offset was then applied to subsequent bulk samples to provide more realistic age estimates for the bulk sediment dates (Patterson et al., 2017). However, it should be noted that the offset may change slightly throughout the core.

A multi-proxy approach was used for this study to determine the timing of past fire events. Macroscopic charcoal, loss-on-ignition (LOI), magnetic susceptibility (MS) and tree cores were used to build a record of fire activity, while pollen analysis was used to determine past changes in vegetation. LOI and MS analyses were conducted on both cores at 0.5 cm resolution. LOI was completed on 1-cm^3 subsamples using the methods of Heiri et al. (2001). Magnetic susceptibility was measured using a Bartington MS3 magnetic susceptibility system and a MS2B sensor. The overlap between the Glew gravity core and the Livingston piston cores was determined using LOI, MS and the macroscopic charcoal profiles.

Analysis of subfossil pollen was conducted every 25 cm throughout the combined sediment record following the methods of Faegri et al. (1989). Two *Lycopodium* spore tablets of known quantity (Batch No. 483216; χ = 18582 spores per tablet ± 3820) were added to every 1-cm^3 sediment sample before the chemical processing to enable calculation of pollen and stomata concentrations (Stockmarr, 1971). The sediment matrix was digested using standard acid digestion for palynological studies, including 10% hydrochloric acid, 10% potassium hydroxide, 50% hydrofluoric acid and acetolysis. Sediments were also fine sieved to remove clay and silt particles using a 7µm Nitex® cloth (Cwynar et al., 1979). Coarse sieving was not performed on any of the samples to ensure subfossil stomata were not removed (Pisaric et al., 2003). A minimum of 300 pollen grains were counted for each sample at 400x magnification using a Nikon Eclipse 80*i* microscope. Pollen identifications were made based on a modern reference collection at the Brock University Water and Environment Laboratory (WEL) and several published keys (Bassett et al., 1978; Faegri et al., 1989; McAndrews et al., 1973; Moore et al., 1991). For this study shrub birch (*Betula glandulosa*) and tree birch (*Betula papyrifera)* and white spruce (*Picea glauca)* and black spruce (*Picea mariana)* were combined in the pollen counts. Stomata were counted for each sample and identified using the key developed by Hansen (1995). Stomata were enumerated on the same slides used for pollen identification. Stomata data are presented as presence/absence data. TILIA v2.0.41 was used to generate the pollen diagrams and CONISS was used to conduct a constrained cluster analysis to determine the pollen zones (Grimm, 1987).

Macroscopic charcoal analysis was conducted at contiguous 0.5-cm intervals using 1-cm^3 subsamples. The charcoal preparation and analysis followed the wet sieving method and included deflocculating and bleaching the samples for at least 24 hours before being washed through a 150-µm mesh sieve (Whitlock and Larsen, 2001; Schlachter and Horn, 2010). The remaining material was collected in a petri dish and enumerated. Charcoal morphology was also recorded based on categories derived in Courtney Mustaphi and Pisaric (2014).

The peak detection of macroscopic charcoal was analysed using the software package CHARAnalysis verison 1.1 (Higuera, 2009). CHAR data were resampled to a median sampling interval of 10 years based on sedimentation rates from the Bacon output. CHARAnalysis identified and separated the slowly varying background CHAR (bCHAR) from local peaks (C_{Peaks}) that represent fire events (Higuera et al., 2010). The bCHAR was found using a robust LOWESS smoothing filter, with a 500-year window. The C_{Peaks} were defined locally using the non-transformed, residual model (NR), where the bCHAR was subtracted from the resampled CHAR. The threshold applied was a Gaussian mixture model with a 99th-percentile noise cut off (Higuera et al., 2010). The minimum count analysis was set to 0.05 indicating that the charcoal 75 years before a peak needed less than 5% probability of coming from the same Poisson distribution to be considered a statistically significant peak (Higuera, 2009). A smoothed window of 1000 years was then used to determine fire frequency based on the C_{Peak} within the 1000-year periods. A signal-to-noise index (SNI) was also used to determine the suitability of the record for peak detection analysis. The SNI is a way to quantify the separation between the large peaks and the slowly varying background noise. Kelly et al. (2010) suggest that a charcoal record with a SNI > 3 is suitable for peak detection analysis (Kelly et al., 2010).

1.4 Results

The piston and gravity cores were matched by comparing proxies between the separate cores to determine the depth of overlap in order create a continuous record. The macroscopic charcoal records from the short gravity core and the first drive of the piston core show a clear overlap. The top of the piston core (0cm) aligns with a depth of 27.5cm in the gravity core based on the charcoal, LOI and magnetic susceptibility data (see supplementary data). The overlap between the gravity core and the piston cores resulted in a total adjusted core length of 539.5cm.

1.4.1 Chronology

Results from AMS radiocarbon dating on ten samples are summarized in Table 1. These dates and the accepted age of the WRA were used to build the age-depth model (Figure 3). The base of the Spindly Pine Lake sediment core was deposited at ~12450 yr BP. The core top, representing the sediment-water interface, was observed to have been captured and preserved during core collection. Therefore, the Spindly Pine Lake sediment core provides a continuous record of the full Holocene epoch in southern Yukon.

The chronology indicates changing sedimentation rates throughout the record. In the early Holocene, sedimentation rates were slow at 0.16mm/year. Sedimentation rates increased throughout the record to 0.45 mm/year in the middle Holocene and reach their most rapid rates in the modern sediments at 1.35 mm/year. Therefore, each 0.5 cm sampling interval used for macroscopic charcoal, LOI and MS represents ~4 years of deposition during the modern sediments, ~11 years throughout the middle Holocene and ~31 years in the early Holocene when sedimentation rates were slower.

1.4.2 Sedimentology

The magnetic susceptibility values were low throughout the majority of the record, typically <10 × 10^{-6} SI (Figure 4). Small, occasional peaks could have resulted from erosion events in the catchment. The large peak of 238 × 10^{-6} SI at 158 cm represents the WRA deposit. Smaller peaks between 158 cm and ~170 cm represent samples where the denser WRA material has migrated downcore into the less dense gyttja below (Beierle and Bond, 2002). MS reached a maximum value of 368 × 10^{-6} SI at the bottom of the core (539.5-cm). Sediment at this depth abruptly transitions from gyttja to silty clay that was likely deposited at the termination of the last glaciation and during the formation of Spindly Pine Lake.

Water content is high throughout the sediment core, typically ranging from 80 to 84% and reaching 92 to 99% at the sediment water interface. Water content is comparably lower at 158 cm (~32%) in association with the WRA deposit and in the basal sediments of the core (~14%) where silty clays are dominant. The sudden drop in water content at 48 cm can be attributed to water loss during storage of the piston core, which was collected ~10 years before analysis, rather than to environmental effects impacting the record. LOI is relatively high (50-60%) throughout the record, confirming the lake sediment is dominated by gyttja. Steep declines in organic content, to ~3%, occur in association with the WRA deposit at 158 cm and the silty glacial clay at the base of the sediment core. The organic content increases to its maximum values (60-80%) in the uppermost part of the sediment profile (13 cm to the surface), suggesting that Spindly

Pine Lake is currently more productive than at any other point during the Holocene. Carbonate content is low throughout the record (<5%), with a maximum value of ~10% at 116.5 cm depth in the core.

1.4.3 Fire History

Analysis of the full record from Spindly Pine Lake indicates macroscopic charcoal concentrations ranged from 0 to 441 pieces cm^{-3} and averaged 25.5 pieces cm^{-3}. CHAR ranged from 0 to 15 pieces cm^{-2} $year^{-1}$ with a mean of 1 piece cm^{-2} $year^{-1}$ (Fig. 5). Periods with no charcoal present occurred in the early Holocene (~12,450-11,100 yr BP), during which the sediment record was dominated by silty clay. The highest macroscopic charcoal concentrations in the entire record occurred at ~6000 yr BP (398 cm) and contained 441 pieces of charcoal per cm^3. Based on the macroscopic charcoal record, a total of 91 fire events were identified ~12,449 yr BP and AD 2016. The Weibull fitted FRI distributions passed a one-sample Kolmogorov–Smirnov goodness of fit test with $\rho > 0.05$, indicating that the FRIs are normally distributed . The mFRI is 120 years with a 95% confidence interval of 100-142 years (Fig. 5c). Fire frequency ranged from 0 to 14 fires per 1000 years (Fig. 7c) with periods of decreased fire frequency occurring between 7000-6000 yr BP and 2500-1250 yr BP. A significant increase in fire frequency occurred at ~1000 yr BP. The global SNI value for the record is 6.83, and the local SNI is only <3 in the early Holocene when there was no fire activity. After 10,500 yr BP the local SNI is >3 with a maximum value of 15.3 (Fig. 7d). This suggests that the record is suitable for peak detection analysis.

The mFRI (120 years) for the entire Holocene is similar to other long-term estimates (Higuera et al. 2009; Edwards et al. 2015) ranging between ~100 to 300 years. However, the FRI distribution (Fig. 5c) indicates the area around Spindly Pine Lake has also burned more frequently in the past, with numerous occurrences of two or more fires within a century. The FRIs varied throughout the record with longer FRIs in the early Holocene and shorter FRIs in the late Holocene. The FRIs were also calculated for the four different pollen zones (Figure 6). Zone 1 had the least amount of fire activity with only 3 fires occurring within the ~2500 year period between 12,450 yr BP and 10,000 yr BP. The time between fires for this zone was 170 and 790 years, however, due to the small number of fires in Zone 1 CHARAnalysis could not calculate full fire statistics for pollen Zone 1. Zone 2 (10,000 yr BP to 3850 yr BP) had the longest mFRI (124 years) of the three zones for which fire statistics were determined. This zone had slightly longer FRIs, but was the most similar to the long-term Holocene average. Fire activity increased during Zone 3 (3850 yr BP to 2000 yrBP) with a mFRI of 85 years. This was significantly different from Zone 2 and the shortest mFRI for the four pollen zones identified in the sediment record. Fire activity declined only slightly during pollen zone 4 (2000 yr BP to AD 2016), with a mFRI of 88 years.

Analysis of charcoal morphotypes (Figure 8) indicates the type of charcoal that was produced by fires throughout the Holocene was generally consistent throughout the record. The most prominent types found are the wood categories A3 and B2, described in Courtney Mustaphi and Pisaric (2014). Charcoal morphotype A3 represented ~40-50% of the charcoal pieces examined on average. Charcoal morphotype B2 represented ~20-30%. During the mid-Holocene period from ~5000 yr BP to 2000 yr BP, charcoal morphology shifts slightly and becomes less A3 and B2 dominant, with an increase in A2, B1, B5, B6, C1, C5 and C7. The largest change in relative percent occurred in A3, dropping ~25%. From ~5000 yr BP to 2000 yr BP there is a larger variety of material being burned than the rest of the record. This is consistent with the pollen analysis. There appears to be greater pollen richness from ~5000 yr BP to 2000 yr BP than there is throughout the rest of the record, leading to a change in charcoal morphology with the wider range of categories found. Further, between ~5000 and ~2000 yr BP, there are many high magnitude peaks, including some of the largest peaks present in the record, suggesting more severe fires and more material burned.

1.4.4 Vegetation

Analysis of subfossil pollen samples identified four main vegetation zones during the Holocene based on the Spindly Pine Lake sediment record (Figure 9). These are summarized as follows.

Zone 1: ~12,450 yr BP to 10,000 yr BP (539.5 cm to 500 cm)

Zone 1 represents the onset of the Holocene at Spindly Pine Lake. Pollen from Zone 1 is dominated by shrubs, in particular *Betula* which accounts for ~70% of the pollen rain. *Alnus* pollen contributes ~10% of the pollen rain in Zone 1. *Salix*, *Artemisia* and Poaceae are also relatively abundant, with each of these pollen types accounting for ~5% of the pollen rain in Zone 1. *Picea* pollen is relatively low in Zone 1, but increases rapidly at the transition between pollen zones 1 and 2. The absence of *Picea* stomata in Zone 1 supports the low abundance of *Picea* pollen.

Zone 2: ~ 10,000 yr BP to 3850 yr BP (500 cm to 300 cm)

Picea pollen reaches maximum values of ~60% in Zone 2. *Picea* pollen increases from the bottom of Zone 2 at ~10,000 yr BP before decreasing to ~25% at the top of Zone 2 (~4000 yr BP). This is supported with the presence of *Picea* stomata throughout the zone, indicating that spruce trees were growing in the vicinity of Spindly Pine Lake between 10,000 and 3850 yr BP. During the transition between Zone 1 and 2, *Betula* decreases to ~35% and remains between ~20 to 30% throughout Zone 2. *Alnus* remains relatively abundant in Zone 2, increasing slightly to ~15%. *Pinus contorta* pollen is absent throughout the majority of Zone 2. Lodgepole pine appears at the top of Zone 2 in relatively low abundance, accounting for <5% of the pollen rain.

Zone 3: ~ 3850 yr BP to 2000 yr BP (300 cm to 200 cm)

Zone 3 is marked by the sustained occurrence of lodgepole pine pollen in the sediment record. Lodgepole pine pollen increases throughout Zone 3 from ~5% (~3850 yr BP) to a maximum of 55% of the pollen rain at the top of Zone 3 (~2000 yr BP). *Pinus* stomata are present near the end of Zone 3 at ~2500 yr BP, when *Pinus* pollen reaches ~40% of the pollen rain. This indicates the approximate time when lodgepole pine migrated into the area around Spindly Pine Lake. *Picea* pollen continues to decrease in Zone 3 from ~25% at the start of the zone (~3850 yr BP) to ~10% at the top of the zone (~2000 yr BP). *Betula* remains abundant throughout Zone 3, accounting for ~20% of the pollen rain with a slight decrease to ~15% at the top of Zone 3. *Alnus* pollen was consistent at ~15% throughout Zone 3.

Zone 4: ~ 2000 yr BP to AD 2016 (200 cm to core top)

Zone 4 is characterized by the full expansion of lodgepole pine in the area. Pine dominates this period, increasing to ~80% of the pollen rain throughout Zone 4 (~2000 yr BP to 2016 AD). *Pinus* stomata are also present throughout the uppermost pollen zone, suggesting lodgepole pine was an important component of the vegetation cover surrounding Spindly Pine Lake during this period. *Picea* pollen continued to decrease at the start of Zone 4 to ~5%, where it remains at present. *Picea* stomata were present throughout Zone 4, indicating the local presence of spruce at Spindly Pine Lake. This is supported by current observations of spruce on the landscape around Spindly Pine Lake. *Betula* and *Alnus* decrease in Zone 4, accounting for ~5% of the pollen rain, respectively.

1.4.5 Dendrochronology

Dendrochronological samples of fire scars (Figure 10) collected from trees surrounding Annie Lake, a larger lake <1 km east of Spindly Pine Lake, show evidence of 3 recent fire events (Robillard, 2012). These fires occurred in AD 1725, 1833 and 1892, indicating the last fire in the catchment occurred ~125 years ago. Dates of establishment (5-year bins) based on tree cores collected from mature lodgepole pine and white spruce trees around Spindly Pine Lake suggests the current canopy established at ~ AD 1915. This suggests the current forest around Spindly Pine Lake likely represents post fire establishment after the AD 1892 fire. Interestingly, a single lodgepole pine tree from this site was dated to 179 years old, suggesting this tree survived the 1892 fire and possibly represents regrowth following the 1833 fire.

1.5 Discussion

A 5.39 m sediment core was collected from a small lake in southwest Yukon and analysed for pollen, stomata, macroscopic charcoal and sedimentological parameters. Based on the occurrence of glacial silt at the base of the sediment core and the 10 radiocarbon and tephra dates obtained on material recovered from the sediment core, the record provides an uninterrupted record of environmental and climate change in this region from the end of the last glaciation (McConnell) to the present. The ice sheet began to retreat prior to ~13,000 yr BP and deglaciation was complete prior to ~10,000 yr BP (Jackson et al., 1991). This study region was likely one of the last areas to become ice free during the Cowley stage, one of the later stages in the McConnell deglaciation (Bond, 2004).

1.5.1 Early Holocene: ~12450 yr BP to ~8000 yr BP

After deglaciation the area was dominated by deciduous shrubs, mainly *Betula*. Conifer species were absent during this period (~12450 yr BP to 10,000 yr BP) as *Picea* had not yet migrated into the region. Results from this study indicate fire activity was low and intermittent following deglaciation with low fire frequency (<3 fires per 1000 years). Fire activity increased after 9,500 yr BP (~8 fires per 1000 years). The increase in fire activity was synchronous with the expansion of *Picea* into the area at ~10,000 yr BP, replacing *Betula* as the dominant species. The increase of *Picea* in the region likely lead to an increase in biomass and fuel accumulation, and subsequent increase in fire activity. The arrival of spruce in the area is supported by the occurrence of spruce stomata at the start of Zone 2. Although white spruce (*Picea glauca*) and black spruce (*Picea mariana*) were not differentiated for this study, Cwynar and Spear (1995) show that white spruce makes up the majority of the spruce pollen in southwest Yukon.

1.5.2 Middle Holocene: ~8000 yr BP to ~3000 yr BP

Spruce pollen was most abundant in the record during the middle Holocene between ~8000 yr BP and ~4500 yr BP when it started to decline (Figure 9). Initially, during this decline there was an increase in the abundance of *Betula*, although this was short-lived until ~3300 yr BP when lodgepole pine began to advance into the region. As lodgepole pine migrated north, lodgepole pine pollen increased in abundance and stomata of lodgepole pine were noted in the sediment record in Zone 3.

The middle Holocene can be characterized as a high-severity fire regime as it contained many of the largest fires throughout the entire record based on the number of particles entering the lake. Fire activity increased throughout the middle Holocene, increasing to as many as 10 fires per 1000 years with a FRI of ~95 years at ~5500 yr BP. The highest magnitude fire in the record occurred at ~6000 yr BP with a influx of 441 charcoal pieces per cm^3. This large influx of charcoal followed an extended period of low fire activity in the charcoal record, which could have led to a build up of fuel as a result of the lower fire frequency. This high-severity fire regime occurred while a spruce forest dominated the landscape. During the transition period (~4500 yr BP to ~3000 yr BP), when spruce declined and pine migrated north into the Spindly Pine Lake watershed, there were still several high severity peaks that occurred during this time.

A decrease in fire frequency during the middle Holocene occurred between 7000 – 6000 yr BP when fire frequency decreased to ~5-6 fires per 1000 years with longer FRIs of ~170 years. An increase in black spruce and green alder in southern Yukon between 6500 yr BP and 6000 yr BP is noted from several studies (Keenan and Cwynar, 1992; Cwynar and Spear, 1995) and probably represented a transition to a cooler and wetter climate. These cool and wet conditions probably suppressed fire activity in the region and led to the lower fire frequency in the mid-Holocene. After ~6000 yr BP, fire frequency increased again to ~10 fires per 1000 years.

1.5.3 Late Holocene: ~3000 yr BP to Present

During the late Holocene the expansion of lodgepole pine into southern Yukon was underway. Lodgepole pine populations expanded rapidly via local population expansion, which can be triggered by fire (Edwards, 2015). At Spindly Pine Lake, the expansion of lodgepole pine was likely a response to lodgepole pine extending its range following the end of the last glaciation and higher fire activity, which probably opened up the spruce dominated forests across the landscape.

After the expansion of lodgepole pine, fires became more frequent. The mFRI throughout Zone 4 was 88 years (Figure 9). However, a period of decreased fire activity occurred between 2500 – 1000 yr BP. During this time FRIs lengthened to a mFRI of ~150 years, and several fires during this period had time between fires that exceeded 200 years. This decline was attributed to neoglacial cooling as well as wetter conditions, which is supported by isotopic data derived from a lake sediment record from nearby Jellybean Lake (Anderson et al., 2005; Figure 11). The neoglacial cooling occurred near the end of this period (~1400 yr BP to ~1100 yr BP), resulting in cooler temperatures and regional glacial advances (Anderson et al., 2005; Davis et al., 2016). During the period from 2500 – 1000 yr BP the Aleutian Low pressure system is believed to have been in a prolonged westerly and weak position (Figure 11). This allowed for more precipitation to be carried into central Yukon via this zonal pattern. By comparing the AL with precipitation-to-evaporation ratios derived from $\delta^{18}O$, Anderson et al. (2007) found the westerly and weak position of the AL correlates with wetter conditions in southwest Yukon. Conversely, the more easterly position and stronger AL is associated with drier conditions across southern Yukon. The isotopic data and inferences about the position and strength of the AL derived from them, suggests the period from 2500-1000 yr BP was dominated by a westerly positioned and relatively weak AL, which led to wetter conditions and lower fire activity in the region.

Following the period from 2500 – 1000 yr BP an increase in fire frequency occurred at ~1000 yr BP. This represented the most active period in terms of fire events throughout the entire Holocene. Fire frequency increased to ~13 fires per 1000 years at ~1000 yr BP with short FRIs of ~70 to 80 years. From ~1000 yr BP to 650 yr BP, there were numerous instances when multiple fires occurred within a century resulting in the shortest FRIs (~20 to 30 years) of the entire record. During this time the AL switched from westerly and weak to easterly and strong (Figure 11), leading to a more meridional pattern and limiting the amount of precipitation moving into central Yukon. In addition to the shift in the position of the AL, this period also coincides with the Medieval Climate Anomaly (MCA; Loehle, 2007; Mann et al., 2012), a period of warmth in the late Holocene that is comparable to current conditions. Therefore, the increased fire activity may be a result of the combined effects of warm and dry conditions from the MCA and changes associated with the AL.

Fire activity decreased again between 600 yr BP to the present. This decrease in fire activity coincides with a shift in the AL to a westerly position and weak condition and the occurrence of the Little Ice Age (LIA; Luckman, 2000; Loehle, 2007; Mann et al., 2012). The LIA led to cooling across many parts of the northern hemisphere, including western Canada, and led to regional glacial advances (Figure 11). The cooler conditions of the LIA likely helped to suppress local fire activity.

The changes in fire frequency that occurred in association with a shifting AL and the MCA and LIA suggests that top down controls (i.e., climate) are important drivers of fire in this region. Similarly, the significant shift in mFRI when pine expanded into southwest Yukon highlights the importance that bottom up controls (i.e., vegetation) also have on fire occurrence in southwest Yukon.

1.5.4 Current Conditions

Tree establishment dates and fire scar data from directly around Spindly Pine Lake and nearby Annie Lake indicate it has been 125 years since the last fire in the Spindly Pine Lake catchment. The limited fire activity in the modern record, relative to Zone 4, is likely a result of current fire management and prevention practices that contribute to fire suppression. Comparison of the time since the last fire in the catchment (125 years) with the mFRI for the entire record (120 years), suggests the area around Spindly Pine Lake is overdue for a large fire. However, the current forest composition is an important consideration as the FRIs did change throughout the record. The current vegetation around the lake is representative of that which occurred throughout Zone 4, with lodgepole pine as the dominant species. Therefore, the mFRI for Zone 4 (88 years) is probably a more accurate comparison than the average mFRI for the entire Holocene and further highlights that the this part of the southern Lakes region of Yukon is much overdue for a large stand-replacing fire event. The risk is heightened due to the fact that fine fuels have now had more than a century to accumulate on this landscape in the absence of fire, exceeding not only the Holocene norm, but also the normal fire activity of the past several thousand years when boundary and vegetation conditions have been similar to those at the present time. Further complicating these fire conditions is the ongoing warming that has occurred in this region throughout the 20th and into the 21st

century. Over the past 50 years temperatures have increased by 2°C in Yukon and they are projected to increase another 2°C over the next 50 years (Streicker, 2016). In addition, the North Pacific Ocean has been in a state of prolonged easterly positioned and strong AL (Figure 11). Several studies (McCoy and Burn, 2005; Flannigan et al., 2009; Flannigan et al., 2013) have predicted a change in the fire regime in response to changing climatic conditions, with increased temperatures leading to higher fire frequency and severity. The fire record from Spindly Pine Lake, especially at ~1000 yr BP, is a useful comparison to portend future fire scenarios for this region. At ~1000 yr BP vegetation and boundary conditions, including the position of the Aleutian Low (Figure 11), were similar to present conditions. The Spindly Pine fire record indicates these conditions led to some of the highest fire activity recorded in the Spindly Pine Lake charcoal record during the Holocene. Similarly, the largest fire event(s) recorded in the Spindly Pine Lake charcoal record at ~6000 yr BP, occurred after a period of prolonged absence of fire on the landscape and an easterly positioned AL. Similar conditions are present at the current time across southern Yukon. In addition, continued and predicted warming due to climate change will further exacerbate the potential for large fires in southern Yukon in the coming decades.

1.6 Conclusions

This study presents a full Holocene record of fire history conducted at sub-decadal to decadal resolution in concert with a robust age-depth model. Results suggest that climate has been an important top-down influence on fire regimes in this area, with the Aleutian Low pressure system in particular being an important climatic driver of fire across this region. Periods of increased fire frequency coincide with a strong and easterly positioned AL, while periods of decreased fire frequency coincide with a weak and more westerly positioned AL. In addition, large shifts in the fire regime also occurred in association with known changes in climate, most notably the Medieval Climate Anomaly and the Little Ice Age.

Edwards et al. (2015) concluded that fire may have triggered a rapid expansion of lodgepole pine in southwest Yukon. The results of the current study support this suggestion, with the expansion of lodgepole pine at Spindly Pine Lake occurring synchronously with a shift to lower mFRIs. Prior to lodgepole pine becoming established in this region, the mFRI was ~124 years. Following the expansion of lodgepole pine the mFRI declined to ~85 years and has remained in this range since lodgepole pine became fully established and dominant in the forests around Spindly Pine Lake. It is important to recognize however, the important role that climate plays in controlling fire regimes in southwest Yukon, because even during the initial expansion of lodgepole pine, a prolonged period of weak and westerly positioned AL lead to decreased fire activity.

The highest magnitude fire in the Spindly Pine Lake charcoal record followed a period of decreased fire activity. This supports the notion that bottom up controls on fire occurrence, through controls on the accumulation of fine fuels, can also be an important factor controlling fire regimes. The distribution of FRIs in this study are in agreement with previous estimates of FRIs for the boreal forest, albeit at the lower end of previous estimates. When factoring in different vegetation types, the estimates of mFRI decrease further depending on which conifer tree species are present. In particular, as species such lodgepole pine increase in importance and dominance on the landscape, fire return intervals shorten dramatically. This information is important for forest managers and planners involved in the assessment and management of fire in these fire-prone landscapes in southern Yukon. The results from this study suggest the landscape around Spindly Pine Lake is overdue for a fire event. Given the warming that has occurred across Yukon during the past 50 years, the susceptibility of the landscape to the occurrence of a major fire is further increased. Unfortunately, it is unlikely that the conditions around Spindly Pine Lake are anomalous across Yukon and certainly many other regions are probably also overdue and highly susceptible to future fire events as the mature lodgepole pine forest extends well beyond the Spindly Pine region. The results from this study provide insights about past fire activity in Yukon during periods of warmer conditions and similar vegetation scenarios to those occurring in Yukon today. These results suggest future fire scenarios in Yukon will be severe.

REFERENCES

Anderson, L., Abbott, M. B., Finney, B. P., & Burns, S. J. (2005). Regional atmospheric circulation change in the North Pacific during the Holocene inferred from lacustrine carbonate oxygen isotopes, Yukon Territory, Canada. *Quaternary Research*, 64(1), 21-35.

Anderson, L., Abbott, M. B., Finney, B. P., & Burns, S. J. (2007). Late Holocene moisture balance variability in the southwest Yukon Territory, Canada. *Quaternary Science Reviews*, 26(1), 130-141.

Bassett, I. J., Crompton, C. W., & Parmelee, J. A. (1978). An atlas of airborne pollen grains and common fungus spores of Canada. Printing and Publishing Supply and Services Canada.

Beierle, B., & Bond, J. (2002). Density-induced settling of tephra through organic lake sediments. *Journal of Paleolimnology*, *28*(4), 433-440.

Blaauw M and Christen JA (2011). Flexible paleoclimate age-depth models using an autoregressive gamma process. *Bayesian Analysis* 6: 457–474.

Blaauw, M., & Christen, J. A. (2013). Bacon Manual e v2. 2. Blaauw, M., Wohlfarth, B., Christen, JA, Ampel, L., Veres, D., Hughen, KA, Preusser, F., et al.(2010),— Were last glacial climate events simultaneous between Greenland and France, 3 87œ394.

Bond, J. D. (2004). Late Wisconsinan McConnell glaciation of the Whitehorse map area (105D), Yukon. *Yukon Exploration Geology*, *2003*, 73-88.

Bourgeau-Chavez, L. L., Alexander, M. E., Stocks, B. J., & Kasischke, E. S. (2000). Distribution of forest ecosystems and the role of fire in the North American boreal region. *Fire, climate change, and carbon cycling in the boreal forest*, 111-131.

Cleveland WS (1979) Robust locally weighted regression and smoothing scatterplots. Journal of the American Statistical Association 74, 829–836.

Cwynar, L. C., Burden, E., & McAndrews, J. H. (1979). An inexpensive sieving method for concentrating pollen and spores from fine-grained sediments. Canadian *Journal of Earth Sciences*, 16(5), 1115-1120.

Cwynar, L., & Spear, R. (1995). Paleovegetation and paleoclimatic changes in the Yukon at 6 ka BP. *Géographie physique et Quaternaire*, 49(1), 29-35.

Davis, E. L., Mustaphi, C. J. C., Gall, A., Pisaric, M. F., Vermaire, J. C., & Moser, K. A.

(2016). Determinants of fire activity during the last 3500 yr at a wildland–urban interface, Alberta, Canada. *Quaternary Research*, *86*(3), 247-259.

Davies, L. J., Jensen, B. J., Froese, D. G., & Wallace, K. L. (2016). Late Pleistocene and Holocene tephrostratigraphy of interior Alaska and Yukon: Key beds and chronologies over the past 30,000 years. *Quaternary Science Reviews*, 146, 28-53.

Edwards, M., Franklin-Smith, L., Clarke, C., Baker, J., Hill, S., & Gallagher, K. (2015). The role of fire in the mid-Holocene arrival and expansion of lodgepole pine (Pinus contorta var. latifolia Engelm. ex S. Watson) in Yukon, Canada. *Holocene*, *25*(1), 64-78.

Flannigan, M., Cantin, A. S., de Groot, W. J., Wotton, M., Newbery, A., & Gowman, L. M. (2013). Global wildland fire season severity in the 21st century. *Forest Ecology and Management*, *294*, 54-61.

Flannigan, M. D., Logan, K. A., Amiro, B. D., Skinner, W. R., & Stocks, B. J. (2005). Future area burned in Canada. *Climatic change*, 72(1), 1-16.

Flannigan, M., Stocks, B., Turetsky, M., & Wotton, M. (2009). Impacts of climate change on fire activity and fire management in the circumboreal forest. *Global Change Biology*, 15(3), 549-560.

Faegri, K., Kaland, P. E., & Krzywinski, K. (1989). Textbook of pollen analysis (No. Ed. 4). John Wiley & Sons Ltd.

Gavin, D. G., Hu, F. S., Lertzman, K., & Corbett, P. (2006). Weak climatic control of stand-scale fire history during the late Holocene. *Ecology*, *87*(7), 1722-1732.

Gajewski, K., Bunbury, J., Vetter, M., Kroeker, N., & Khan, A. H. (2014). Paleoenvironmental studies in southwestern Yukon. *Arctic*, *67, Suppl. 1*58-70.

Glew, J.R., Smol, J.P., & Last, W.M. (2001). Sediment Core Collection and Extrustion. In W.M. Last & J.P. Smol (eds.), 2001. *Tracking Environmental Change Using Lake Sediments. Volume 1: Basin Analysis, Coring and Chronological Techniques.* Dordrect: Kluwer Academic Publishers, 2001, pp. 73-105.

Government of Canada. (2017). *Historical Climate Data.* Retrieved from http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=1617&autofwd=1

Grimm, E. C. (1987). CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computers & Geosciences*, 13(1), 13-35.

Hansen, B. C. (1995). Conifer stomate analysis as a paleoecological tool: an example from the Hudson Bay Lowlands. *Canadian Journal of Botany*, *73*(2), 244-252.

Heiri, O., Lotter, A., & Lemcke, G. (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal Of Paleolimnology*, *25*(1), 101-110.

Higuera PE, Brubaker LB, Anderson PM et al. (2009) Vegetation mediated the impacts of postglacial climate change on fire regimes in the south-central Brooks Range, Alaska. *Ecological Monographs 79*: 201–219.

Higuera, P. (2009). CharAnalysis 0.9: Diagnostic and analytical tools for sediment charcoal analysis. User's Guide, Montana State University, Bozeman, MT.

Higuera, P. E., Gavin, D. G., Bartlein, P. J., & Hallett, D. J. (2010). Peak detection in sediment–charcoal records: impacts of alternative data analysis methods on fire-history interpretations. *International Journal of Wildland Fire*, 19(8), 996-1014.

IPCC, 2014: Summary for Policymakers, *In: Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer,O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B.Kriemann, J. Savolainen, S. Schl.mer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jackson, L., Ward, B., Duk-Rodkin, A., & Hughes, O. (1991). The last Cordilleran ice sheet in southern Yukon Territory. *Géographie physique et Quaternaire*, 45(3), 341-354.

Johnson, J.A. (1992). *Fire and Vegetation Dynamics: Studies from the North American boreal forest*. New York: Cambridge University Press.

Johnstone, J. F., & Chapin, F. S. (2006). Fire interval effects on successional trajectory in boreal forests of northwest Canada. *Ecosystems*, 9(2), 268-277.

Johnstone, J. F., McIntire, E. J., Pedersen, E. J., King, G., & Pisaric, M. J. (2010). A sensitive slope: estimating landscape patterns of forest resilience in a changing climate. Ecosphere, 1(6), 1-21.

Keenan, T. J., & Cwynar, L. C. (1992). Late Quaternary history of black spruce and grasslands in southwest Yukon Territory. *Canadian Journal of Botany*, *70*(7), 1336-1345.

Kelly, R.F., P.E. Higuera, C.M. Barrett, and F.S. Hu. (2011). A signal-to-noise index to quantify the potential for peak detection in sediment-charcoal records. *Quaternary Research, 75: 11-17.*

Loehle, C. (2007). A 2000-year global temperature reconstruction based on non-treering proxies. *Energy & Environment*, 18(7), 1049-1058.

Luckman, B. H. (2000). The little ice age in the Canadian Rockies. *Geomorphology*, *32*(3), 357-384.

MacDonald, G. (2003). Biogeography: Introduction to Space. Time and Life. Wiley, New York.

Mann, M. E., Zhang, Z., Rutherford, S., Bradley, R. S., Hughes, M. K., Shindell, D., Ammann, C., Faluvegi, G. & Ni, F. (2009). Global signatures and dynamical origins of the Little Ice Age and Medieval Climate Anomaly. *Science*, 326(5957), 1256-1260.

McAndrews, J. H., Berti, A. A., & Norris, G. (1973). Key to the Quaternary pollen and spores of the Great Lakes region.

McCoy, V. M., & Burn, C. R. (2005). Potential alteration by climate change of the forest-fire regime in the boreal forest of central Yukon Territory. *Arctic*, 276-285.

Mock, C. J., Bartlein, P. J., & Anderson, P. M. (1998). Atmospheric circulation patterns and spatial climatic variations in Beringia. International Journal of Climatology, 18(10), 1085-1104.

Moore, P. D., Webb, J. A., & Collison, M. E. (1991). Pollen analysis. Blackwell scientific publications.

Mustaphi, C. J. C., Davis, E. L., Perreault, J. T., & Pisaric, M. F. (2015). Spatial variability of recent macroscopic charcoal deposition in a small montane lake and implications for reconstruction of watershed-scale fire regimes. *Journal of Paleolimnology*, 54(1), 71-86.

Mustaphi, C. J. C., & Pisaric, M. F. (2014). A classification for macroscopic charcoal morphologies found in Holocene lacustrine sediments. *Progress in Physical Geography*, 38(6), 734-754.

Mustaphi, C. C., & Pisaric, M. F. (2014). Holocene climate-fire-vegetation interactions at a subalpine watershed in southeastern British Columbia, Canada. *Quaternary Research*, (2), 228-239.

Patterson, R. T., Crann, C. A., Cutts, J. A., Courtney Mustaphi, C. J., Nasser, N. A., Macumber, A. L., & ... Falck, H. (2017). New occurrences of the White River Ash (east lobe) in Subarctic Canada and utility for estimating freshwater reservoir effect in lake sediment archives. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *477*1-9.

Payette, S. (1992). Fire as a controlling process in the North American boreal forest. In A systems analysis of the boreal forest. Edited by H.H. Shugart, R. Leemans, and G.B. Bonan. Cambridge University Press, Cambridge, U.K. pp. 144–169.

Pisaric, M. F., Holt, C., Szeicz, J. M., Karst, T., & Smol, J. P. (2003). Holocene treeline dynamics in the mountains of northeastern British Columbia, Canada, inferred from fossil pollen and stomata. *The Holocene, 13(2),* 161-173.

Ramsey, C. B. (2009). Bayesian analysis of radiocarbon dates. *Radiocarbon*, *51*(1), 337-360.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Ramsey, C. B., ... & Grootes, P. M. (2013). IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon*, *55*(4), 1869-1887.

Robillard, K. (2012). A 250-year record of forest fire history in Canada's southwestern Yukon. Unpublished undergraduate thesis. Department of Geography and Environmental Studies, Carleton University, Ottawa, ON, Canada.

Schlachter, K. J., & Horn, S. P. (2010). Sample preparation methods and replicability in macroscopic charcoal analysis. *Journal Of Paleolimnology*, (2), 701.

Scudder, G. G. E. (1997). Environment of the Yukon. Insects of the Yukon. Biological Survey of Canada (Terrestrial Arthropods), Ottawa, 13-57.

Smith, C.A.S., Meikle, J.C., & Roots, C.F. (2004). Yukon Southern Lakes. Ecoregions of the Yukon Territory: Biophysical properties of Yukon landscapes, (04-01), 207-218.

Smol, J. P. (2009). Pollution of lakes and rivers: a paleoenvironmental perspective. John Wiley & Sons.

Speer, J. H. (2010). *Fundamentals of tree-ring research*. University of Arizona Press.

Spooner, I. S., Barnes, S., Baltzer, K. B., Raeside, R., Osborn, G. D., & Mazzucchi, D. (2003). The impact of air mass circulation dynamics on Late Holocene paleoclimate in northwestern North America. *Quaternary International,* 108(1), 77-83.

Spracklen, D. V., Mickley, L. J., Logan, J. A., Hudman, R. C., Yevich, R., Flannigan, M. D., & Westerling, A. L. (2009). Impacts of climate change from 2000 to 2050 on wildfire activity and carbonaceous aerosol concentrations in the western United States. *Journal of Geophysical Research: Atmospheres*, 114(D20).

Stockmarr, J. (1971). Tablets with spores used in absolute pollen analysis. *Pollen et spores.*

Stocks, B. J. (2004). Forest fires in the boreal zone: climate change and carbon implications. *Int. For. Fire News*, *31*, 122-131.

Streicker, J. (2016). Yukon climate change indicators and key findings 2015. *Northern Climate ExChange, Yukon Research Centre, Yukon College*.

Trenberth, K. E., & Hurrell, J. W. (1994). Decadal atmosphere-ocean variations in the Pacific. *Climate Dynamics, 9(6),* 303-319.

Veraverbeke, S., Rogers, B. M., Goulden, M. L., Jandt, R. R., Miller, C. E., Wiggins, E. B., & Randerson, J. T. (2017). Lightning as a major driver of recent large fire years in North American boreal forests. *Nature Climate Change, 7(7*), 529-534.

Weber, M. G., & Stocks, B. J. (1998). Forest fires and sustainability in the boreal forests of Canada. *Ambio*, 27(7), 545-550.

Whitlock, C & Larsen, C. (2001) Charcoal as a Fire Proxy. In J.P. Smol, H.J.B. Birks & W. M. Last (eds.), 2001. *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators.* Dordrecht: Kluwer Academic Publishers, 2001, pp. 75-97.

Whitlock, C., P.E. Higuera, D. McWethy, and C.E. Briles. (2010). Paleoecological perspectives on fire ecology: revisiting the fire regime concept. The Open Ecology Journal, 3: 6-23.

Wright HEJ, Mann DH, Glaser PH (1984) Piston corers for peatand lake sediments. Ecology 65:657–659

Yukon Wildland Fire Management. (2005). *2004 Wildland Fire Review: Final Report.* Whitehorse: Yukon Wildland Fire Management.

TABLES AND FIGURES

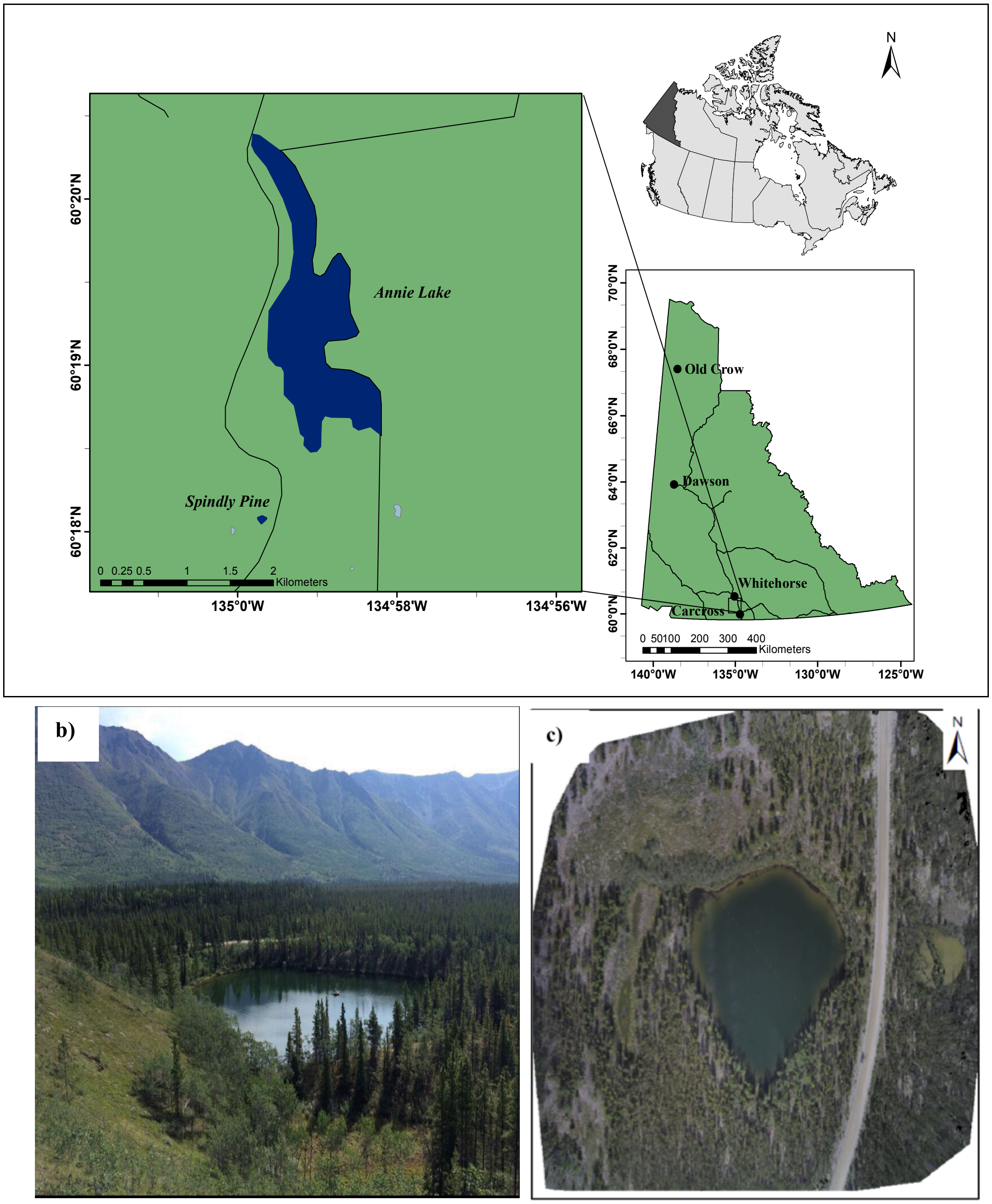


Figure 1 – Location of Spindly Pine Lake, Yukon. **b)** Low-oblique photograph of Spindly Pine Lake showing the closed basin and lack of inflowing/outflowing streams; **c)** Vertical image mosaic of the Spindly Pine lake catchment, acquired using an Unmanned Aerial Vehicle.

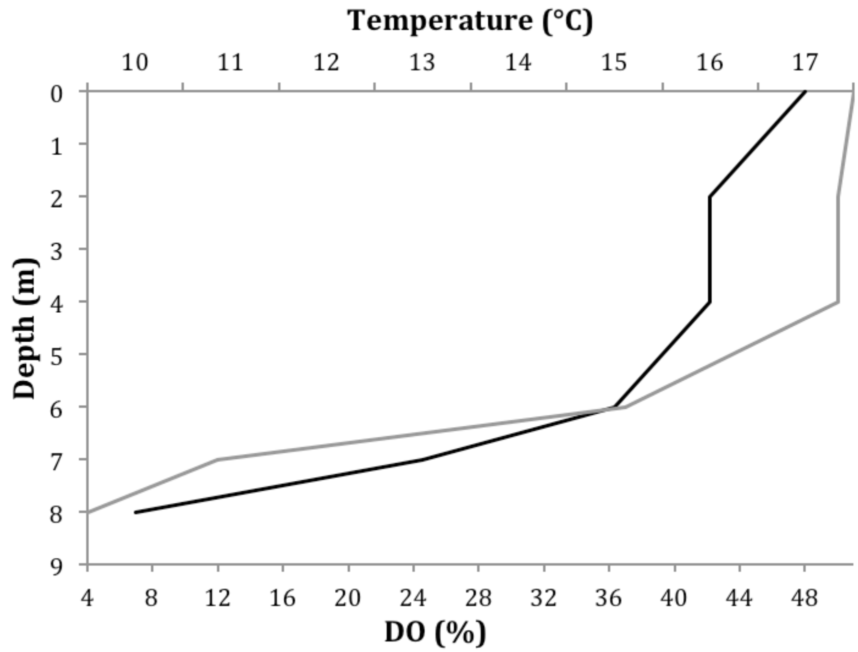


Figure 2 – Temperature (°C; black line) and dissolved oxygen (%; grey line) plotted against water depth for Spindly Pine Lake. Data were collected using a YSI multiparameter sonde August 1st 2016. The lake water is well mixed from the surface down to ~6 m depth. Temperature and dissolved oxygen profiles indicate the presence of a thermocline between 6-8 m depth. Measurements could not be taken below 8m depth (the extent of the YSI cable), so it is uncertain if the lake is completely stratified during the summer months.

Table 1 – Radiocarbon results on bulk sediment and macrofossil samples analysed at the A.E. Lalonde AMS Laboratory in Ottawa, Canada. Calibration was performed using OxCal v4.2.4 (Ramsey, 2009) and the IntCal13 calibration curve (Reimer et al., 2013).

Lab number	Depth (cm)	Material	^{14}C yr BP	Cal yr BP	Adjusted* Cal yr BP
Core top	0			- 66	
WRA	157.5	Tephra		~1170	
UOC – 3173	158	Bulk	1702±36	1625±54	1147
UOC - 3167	243.5	Macro	2639±40	2770±21	2770
UOC - 3168	260.5	Macro	2822±30	2926±37	2926
UOC - 3590	327	Bulk	4382±41	4959±65	4481
UOC - 3169	388.5	Macro	5024±32	5794±71	5791
UOC - 3170	439	Bulk	7032±40	7881±44	7403
UOC - 3171	486.5	Bulk	8446±55	9472±40	8994
UOC -3748[a]	492.5	Charcoal	8520±82	9510±49	9510
UOC -3591[b]	503.5	Bulk	8856±38	9990±121	9512
UOC - 3172	529.5	Bulk	10662±85	12608±119	12130

* Only bulk sediment samples were adjusted by a value of 478 years. This was calculated from the bulk sediment sample (UOC - 3173) that was taken directly after the WRA layer at 158 cm. WRA date from Davies et al., (2016).

[a] UOC – 3748 has larger errors (±82) associated with it due to small sample size.

[b] UOC – 3591 was omitted from the model due to old age offset.

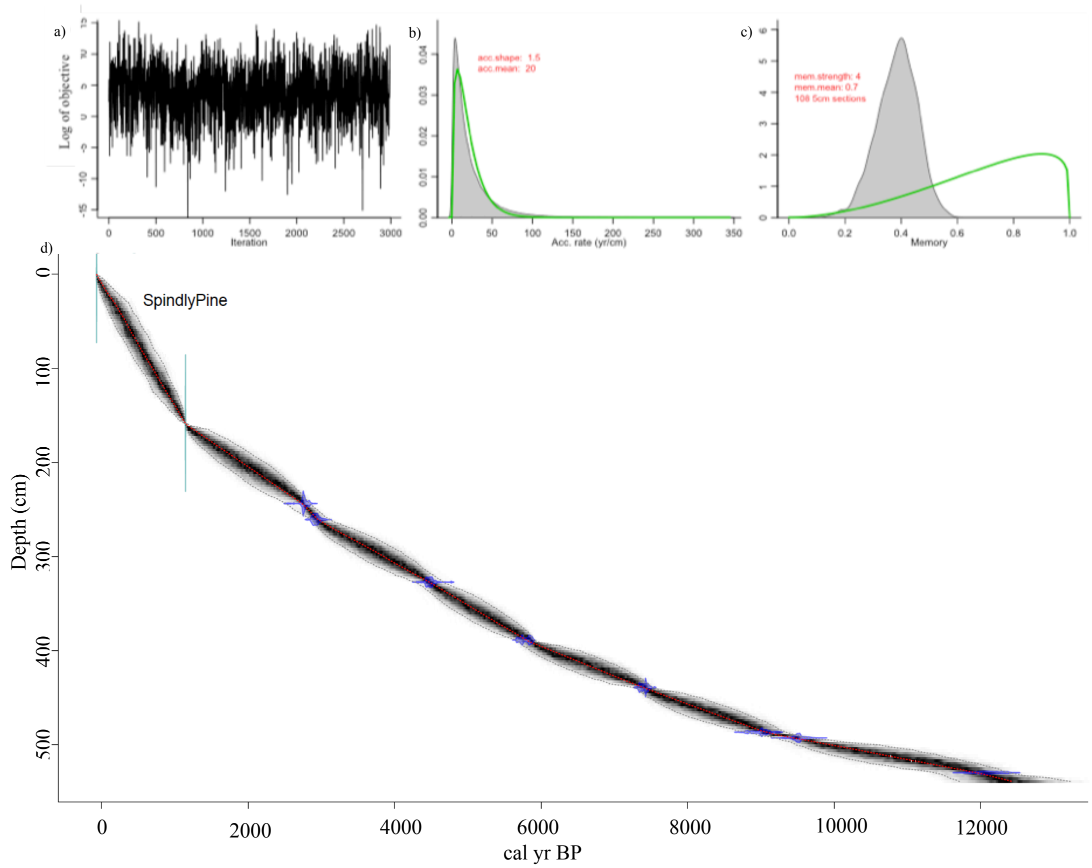


Figure 3 – a) Markov chain Monte Carlo iterations of the BACON output; b) Distribution of accumulation rates; c) memory/autocorrelation, demonstrating how much the accumulation rate at a certain depth in the core is dependent on nearby depths. Low memory indicates changing sedimentation rates throughout the core, while high memory indicates a more smooth, and consistent depositional history; d) Age depth model created with BACON V 2.2 in R Studio. The horizontal green lines represent known dates, blue lines represent the ^{14}C dates and the red line is the model of best fit.

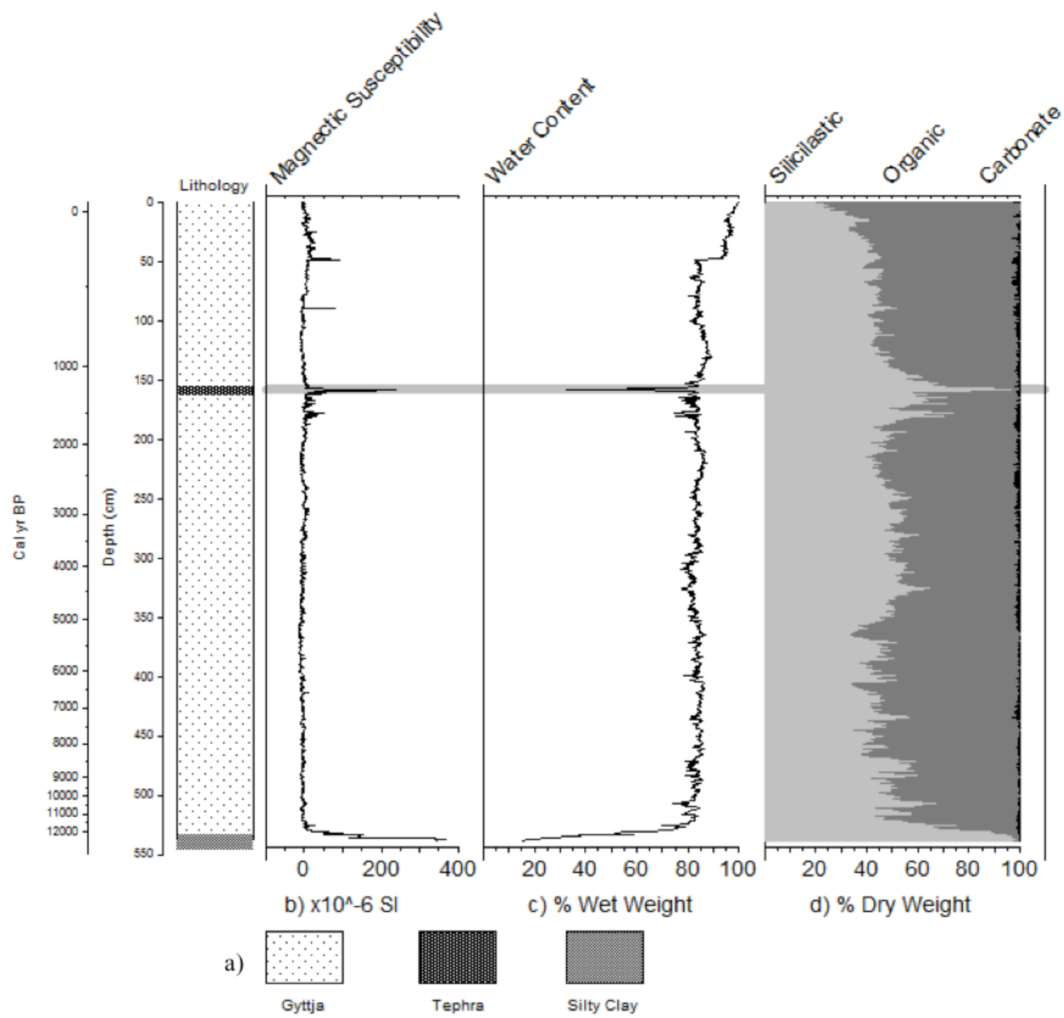


Figure 4 – Sedimentology of the sediment record for Spindly Pine Lake, including a) lithology, b) magnetic susceptibility, c) water content and d) loss-on-ignition. The tephra deposit is represented by the grey horizontal line. Loss-on-ignition shows the water content and dry weight (%) of organic, carbonate and silicilastic material.

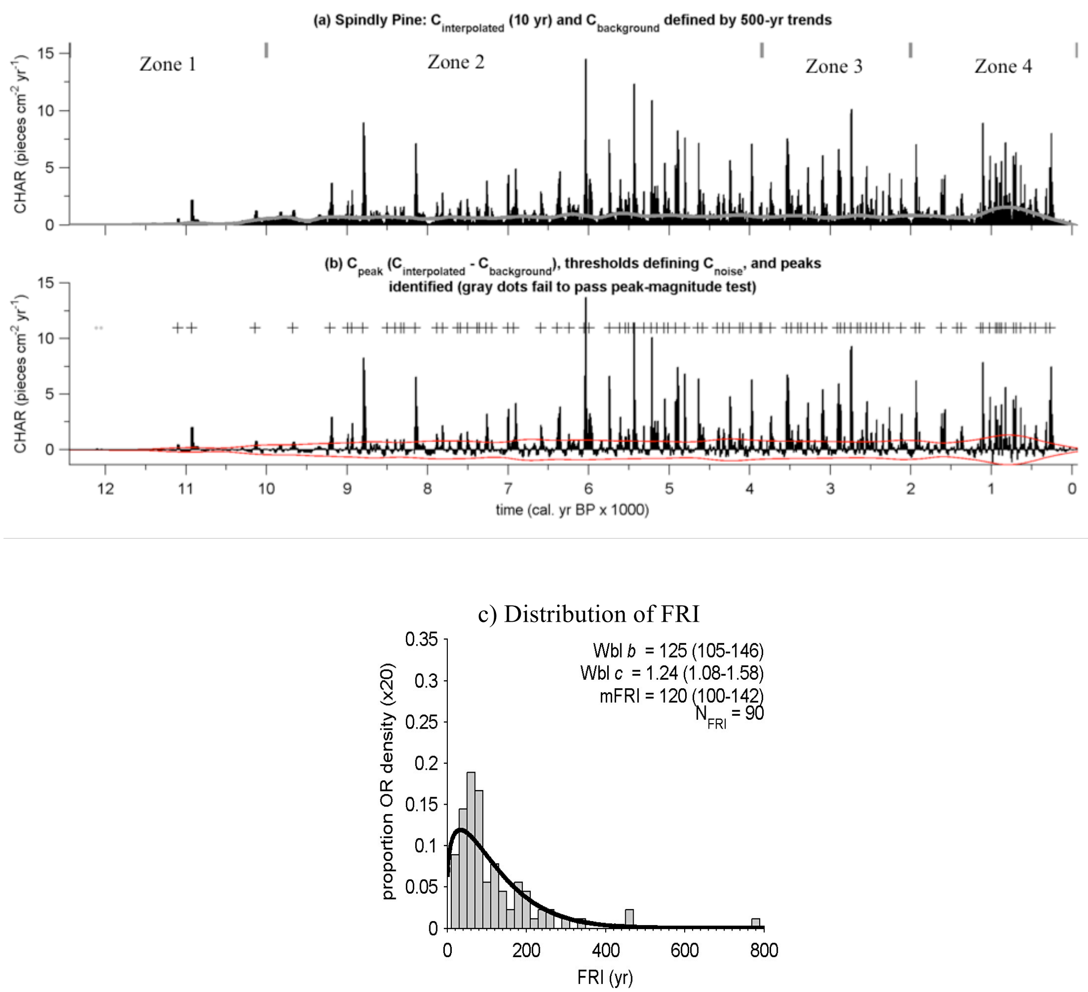


Figure 5 – a) Charcoal accumulation in pieces cm^{-2} year^{-1}; grey line represents background charcoal levels; b) Peak identification with plus (+) symbols representing peaks/fire events and grey dots representing peaks that failed to pass the peak-magnitude test; c) Distribution of fire return intervals (20 year bins) and Weibull model estimates (b and c parameters with 95% CI). The four zones plotted in 5a are based on constrained cluster analyses in CONISS using pollen percentage data.

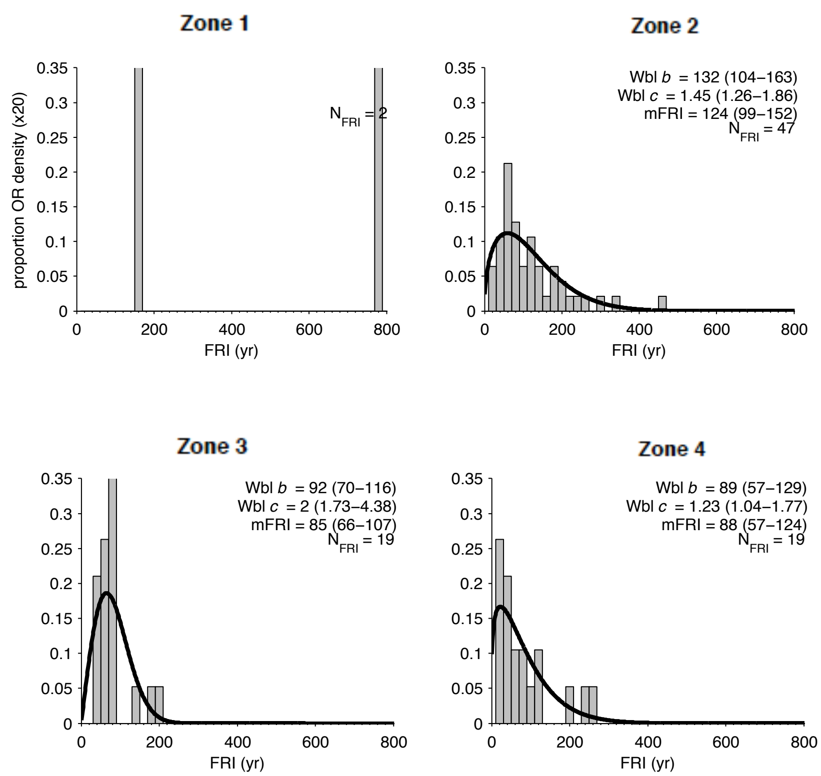
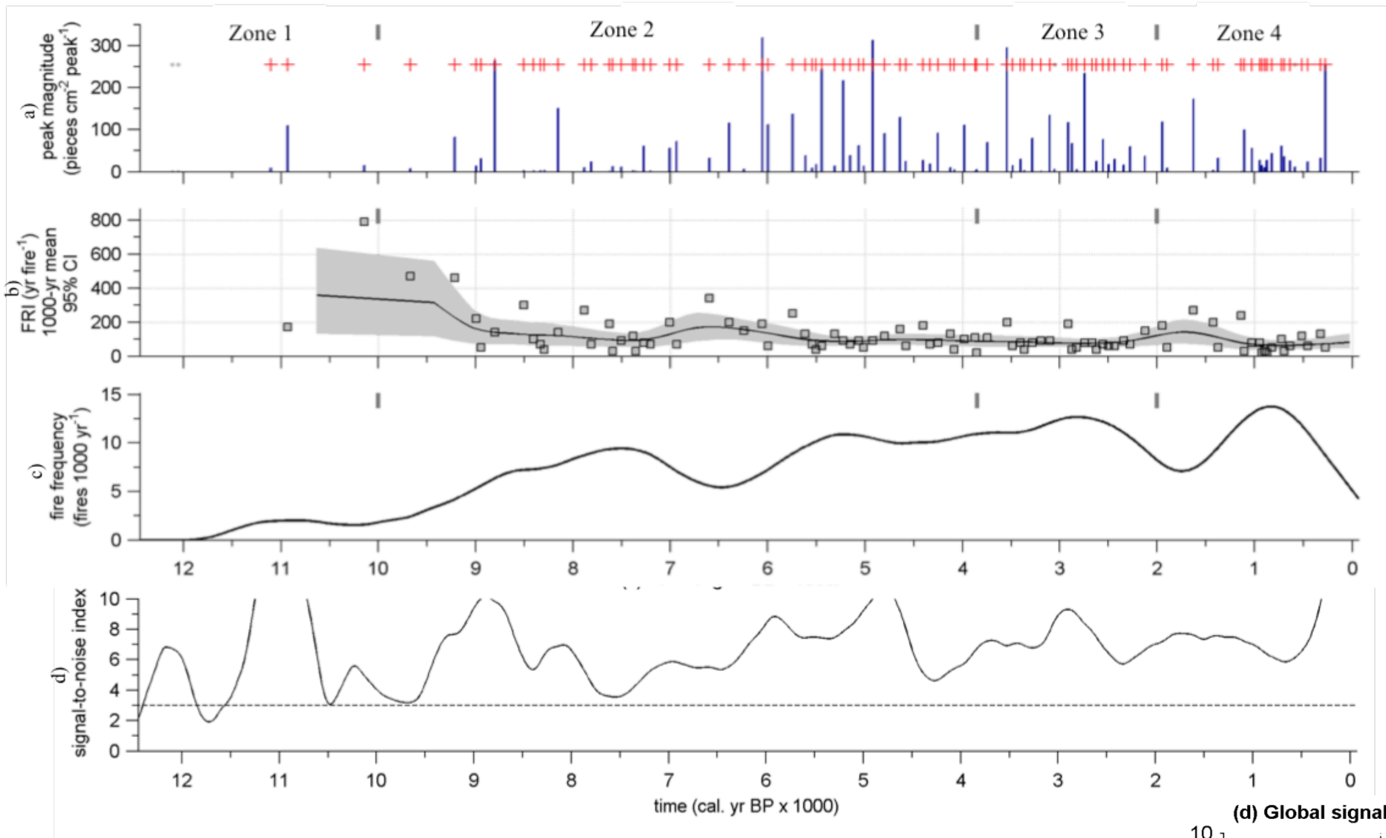


Figure 6 – Mean fire return interval and confidence intervals for the four different pollen zones. Distribution of fire return intervals (20 year bins) and Weibull model estimates (b and c parameters with 95% CI).



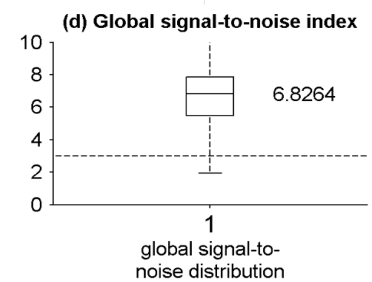


Figure 7 - a) Identified charcoal peaks represented by the red plus symbol and the peak magnitude in dark blue; b) Fire return interval with 95% confidence intervals; c) Smoothed fire frequency (fires per 1000 years); d) Local signal-to-noise index throughout the record with the global signal-to-noise index below.

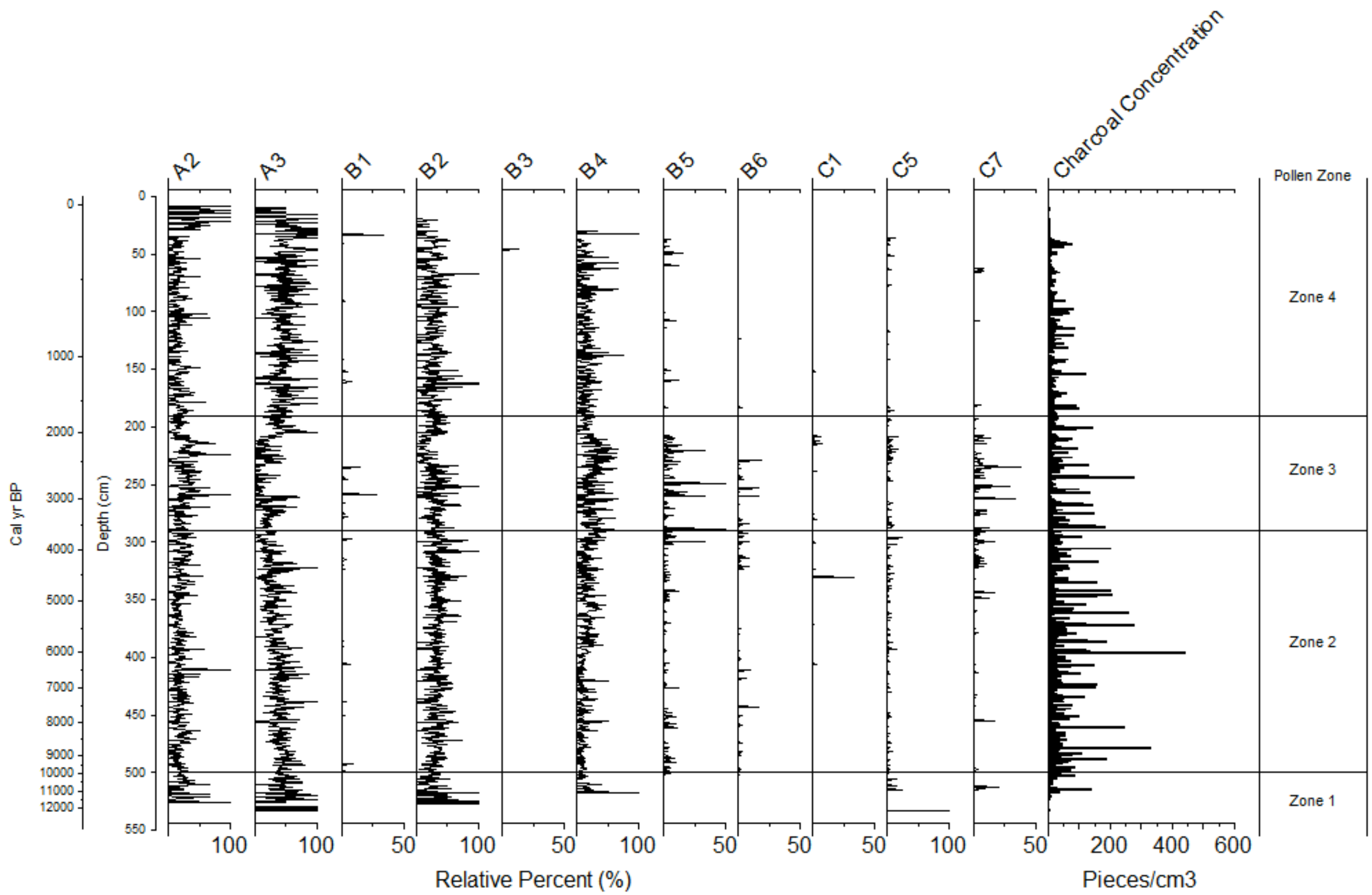
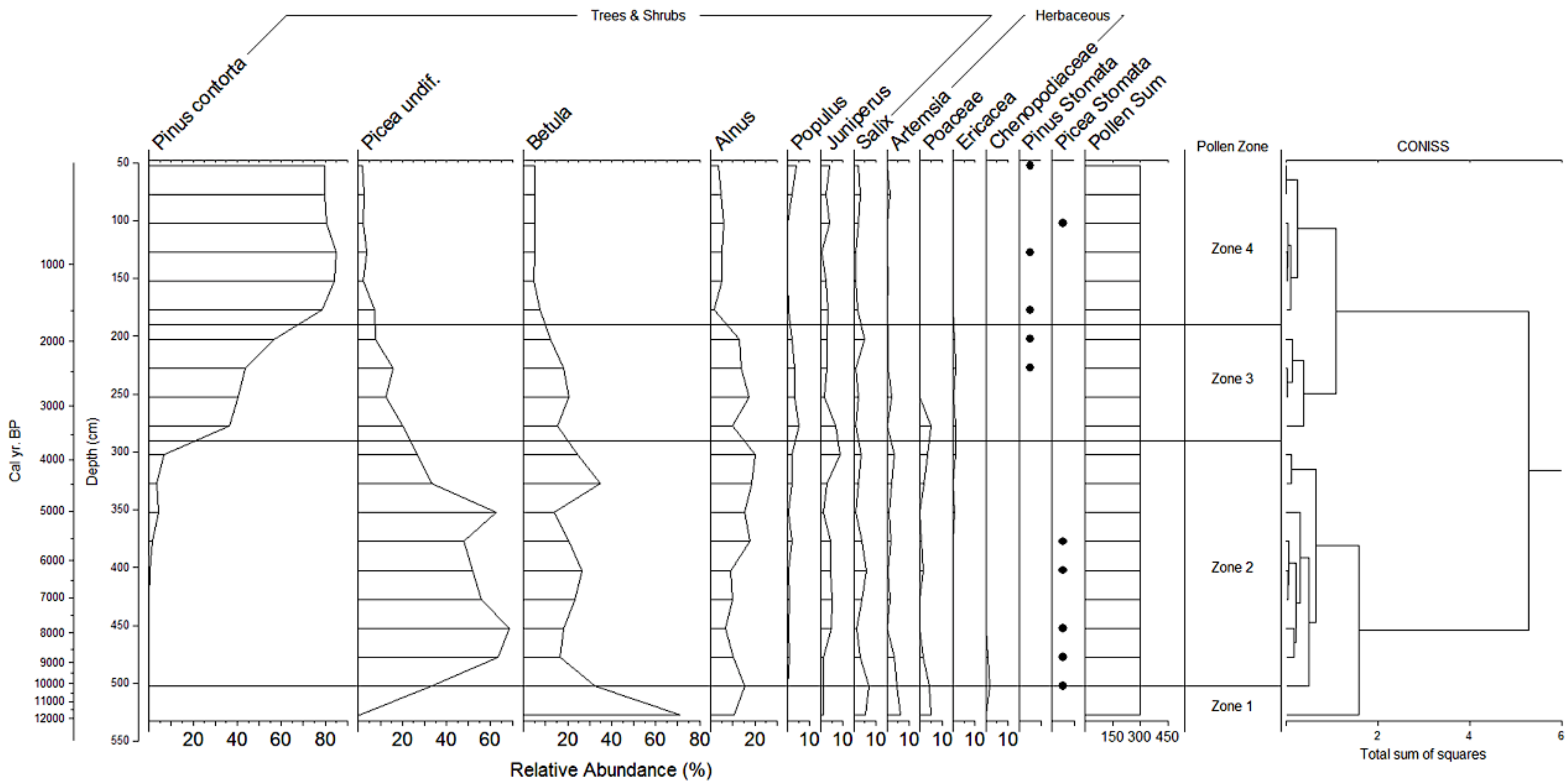
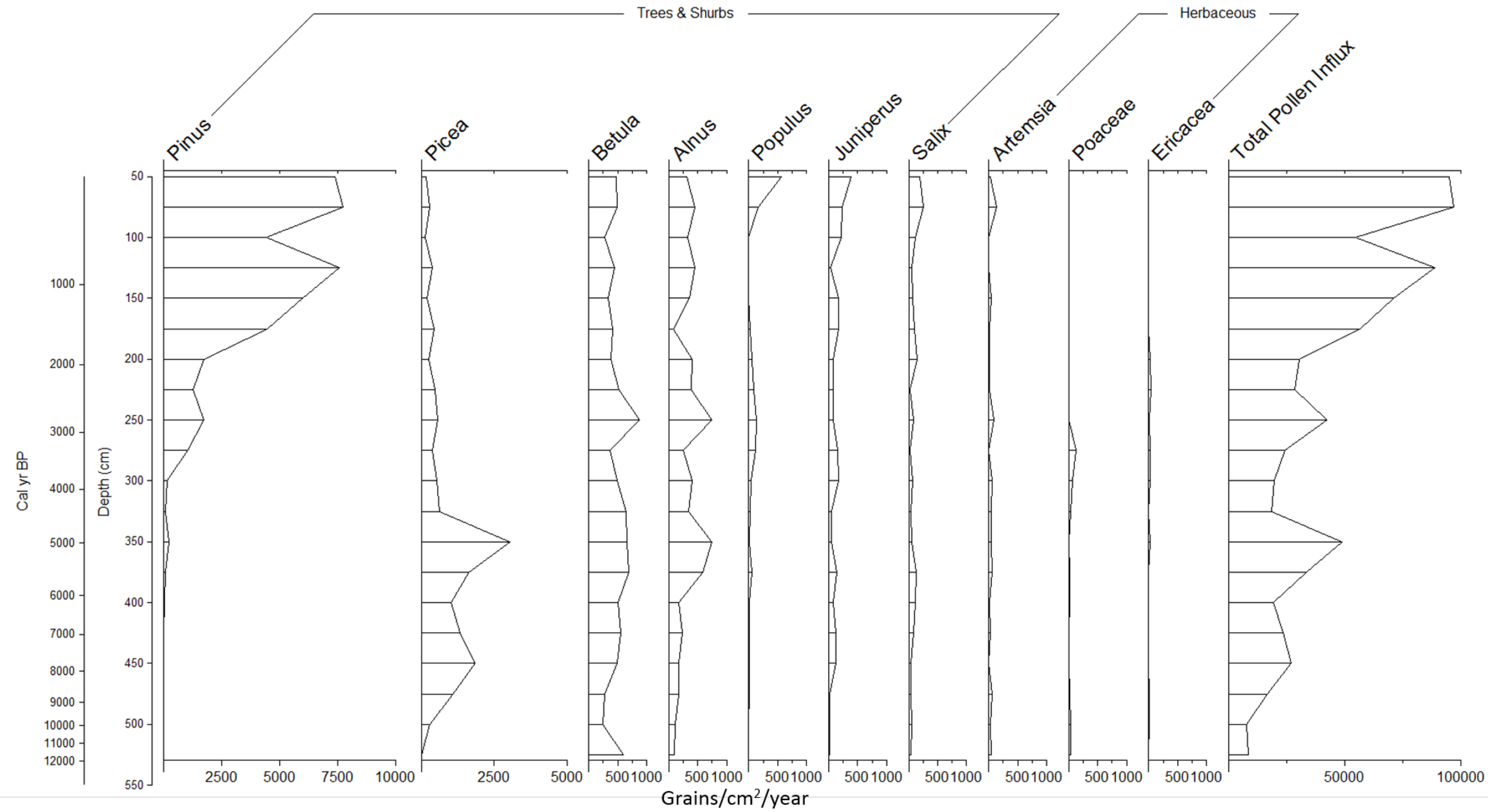


Figure 8 – Charcoal morphology, based on categories derived by Courtney Mustaphi and Pisaric (2014), as well as raw charcoal counts.



Analyst: Tyler Prince
Figure 9 – Relative abundance pollen diagram for Spindly Pine Lake. CONISS was used to determine significant changes in vegetation, which produced 4 pollen zones. Stomata are shown as presence or absence. A total of 300 pollen were counted for all depths.



Analyst: Tyler Prince
Figure 10 – Pollen Influx diagram for Spindly Pine Lake, showing annual deposition of pollen grains.

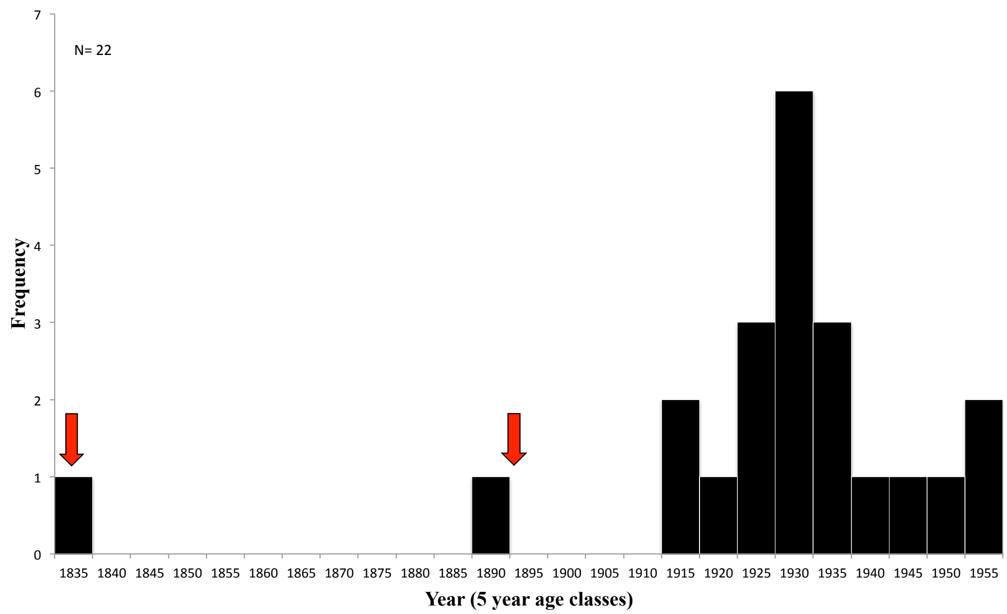


Figure 11 - Histogram showing Spindly Pine Lake stand establishment (5 year bins). Recent fires occurred in AD 1725, 1833 and 1892 and are represented by a red arrow. The recent fires in the catchment were determined by dating fire scars on lodgepole pine trees collected from three sites in the area surrounding Annie Lake, located within 1 km of Spindly Pine Lake (Robillard, 2012). At each site, fire scar dates represent the year of fire based on multiple trees at each site.

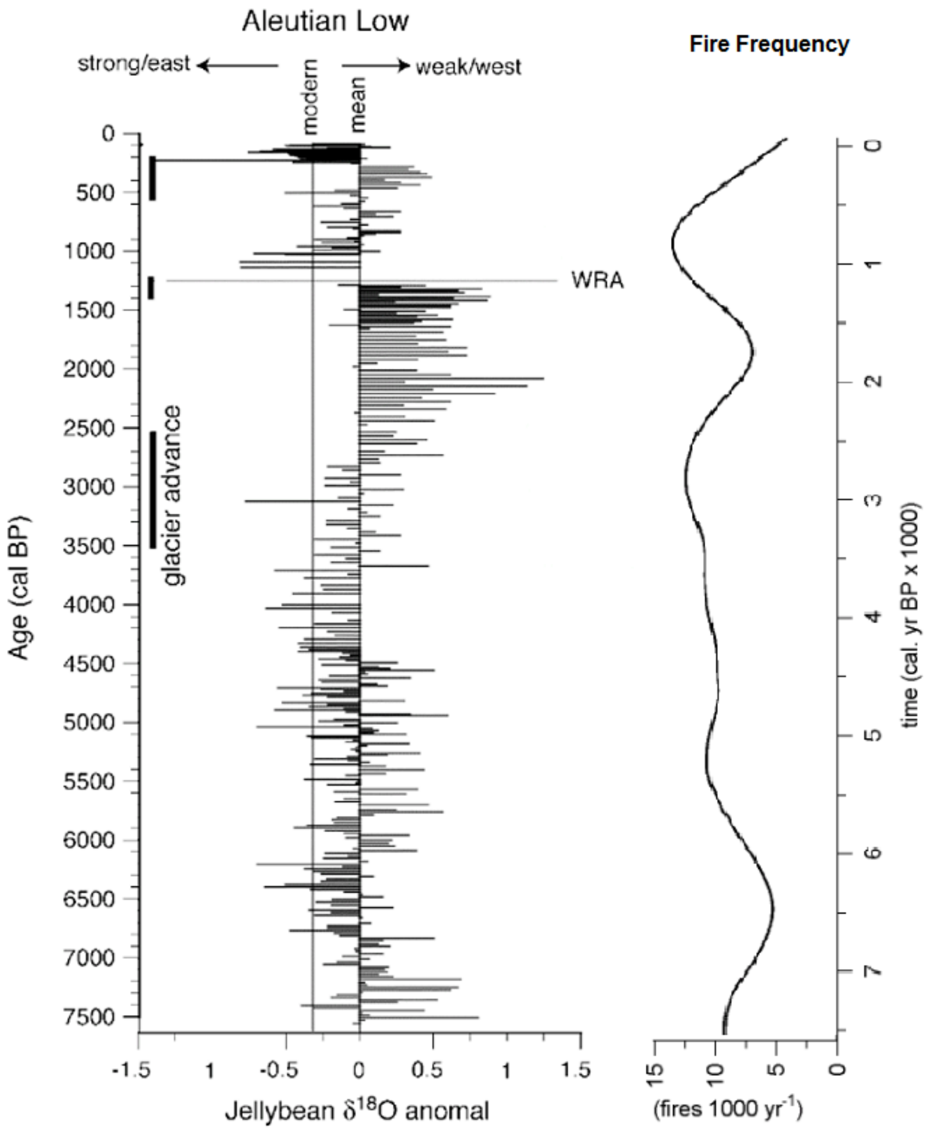


Figure 12 – Reconstruction of Aleutian Low strength/position using $\delta^{18}O$ from Jellybean Lake (Anderson et al., 2005) with fire frequency from Spindly Pine Lake.

CHAPTER FOUR

CONCLUSIONS

4.1 – Conclusions

The objectives of this research were to 1) reconstruct a long-term record of fire history spanning the Holocene using macroscopic charcoal preserved in a lake sediment core collected from Spindly Pine Lake; 2) determine the total number of fires throughout the Holocene and the time between fires to analyze the temporal change in FRIs; 3) identify when lodgepole pine arrives in the region based on the analysis of subfossil pollen preserved in the lake sediment and determine if this change in dominant vegetation cover altered the fire regime; and 4) determine the major climatic drivers of fire in the region. These objectives were achieved by using a sedimentary archive from Spindly Pine Lake, creating a high-resolution record of past environmental change.

The results of this study show that macroscopic charcoal preserved in lake sediment can be a useful tool to build a fire reconstruction. The record showed a total of 91 fires during the Holocene with a mFRI of 120 years. The introduction and subsequent expansion (~3300 yr BP) of lodgepole pine (*Pinus contorta*) was detected in the pollen record and is in agreement with other pollen records from the region. A response to the introduction of lodgepole pine was detected in the record with a significant change in mFRI from ~124 years (pre-pine) to 85 years during the pine expansion and 88 years after pine is fully established.

Although it does appear vegetation change had an effect on the fire regime in the study region, results indicate that fire activity in the area is primarily controlled by top-down climate controls and some influence due to the introduction of lodgepole pine across the region. Results indicate that the Aleutian Low (AL) pressure system is a significant driver of fire activity in southwest Yukon. The AL enhances the rain shadow effect in the Yukon interior, where periods of strong and an easterly positioned AL leads to declines in precipitation for these areas. As the AL weakens and moves west it allows for more precipitation to be carried into the interior of Yukon. The results show the position of the AL impacted fire activity as fire frequency increased during periods of strong/east AL and decreased in periods of weak/west AL. Fire frequency also increased with warming temperatures during the MCA and decreased with cooling temperatures during the LIA. These are important insights considering the recent and anticipated warming due to anthropogenic-induced climate change.

With an increase in greenhouse gas concentrations, anthropogenic-induced climate change may intensify the natural fire regime creating an increase in fire severity, frequency and a longer fire season (Stock et al. 1998). Recent modeling studies (Flannigan et al, 2005; Sprackeen et al., 2009) also support a change in fire regime during the coming years. High severity fires only represent a small percentage of the total annual fires, however they are responsible for the majority of the total area burned. This is a concern with future predictions indicating high severity fires are becoming more common. This will stress the fire management system, which is already exceeding annual budgets. An improvement in fire management and prediction will be needed in order to keep up with the changing fire regime. The boreal forest is valuable both economically and culturally, however the north is also the most sensitive area to climate change and will see the most rapid and significant impacts.

4.2 – Future recommendations

A recent study (Hawthorne et al., 2017) compiled modern charcoal studies from the previous decades to provide an open dataset called the Global Modern Charcoal

Dataset (GMCD). Results of this dataset include 33 charcoal studies that have been conducted in the boreal forest, although there is a clear lack of data from Yukon. The charcoal results from Spindly Pine Lake will begin to fill this gap for the region, recognizing that wildfire is highly variable both spatially and temporally. Therefore, macroscopic charcoal studies needs to be expanded upon across Yukon. It is problematic for forest managers to develop policies based on the current temporally-limited wildfire records, especially considering the fire return intervals can range considerably in the boreal forest, as they may produce incorrect estimates of FRIs for a region.

Additional studies examining the spatial variability of fire regimes across Yukon are needed. The Yukon-Plateau region and the Tintina Trench in particular, experience the most lightning strikes of any region in Yukon. Our understanding of past fire activity across this part of Yukon is lacking. Further, as lodgepole pine continues to expand across Yukon, changing fire regimes should be expected and need to be planned for. Paleo-fire studies can assist with this task.

Additional proxies that could complement the work presented in this study include analyzing fire scars from trees, ephippia, and polycyclic aromatic hydrocarbons (PAHs). The fire scars would be useful to build a record of recent, known fires in the catchment and to infer local climate from growth characteristics of the tree rings. Ephippia may be useful as an indicator of ecosystem response to a fire. The occurrence of these biological remains may be correlated with fire activity and useful to determine how the lake itself is effected by fire activity. Throughout the macroscopic charcoal analysis, it was noted that ephippia were present in the Spindly Pine Lake sediment and possibly more abundant during the peak charcoal deposits. However, ephippia were not quantified therefore this could be an additional proxy that could be analysed in the future.

Analyzing PAHs would add a different perspective to the study by determining potential negative health impacts as a result of forest fire. PAHs are naturally released through the burning of wood during a forest fire and are known to have severe health impacts. Studies show that of the many forms of PAHs, 15 are listed as reasonably anticipated human carcinogens (NTP, 2016). One of these anticipated carcinogens, known as benzo(a)pyrene (BaP), is released during a forest fire. BaP significantly impacts air quality, therefore this can be used as a proxy to assess the impact wildfire has on air quality. This may be of interest for the Yukon as this study suggests the Spindly Pine Lake region is overdue for a large burn. Therefore, Whitehorse and nearby communities such as Carcross may have concern over the health risks associated with a large fire that does not immediately impact these communities. Also, different PAHs are formed at different temperatures and with different fuel sources (NRC, 1983), so additional information about the fuel source and fire intensity/severity could be collected by analyzing PAHs. Further, analyzing PAH composition could be useful to assess fire severity. This could be improved upon by including PAHs to reconstruct the temperature of the fire and better assess fire severity in sediment cores. In addition to fire severity, PAHs could be useful in determining the fuel source of a past fire event. The different types of PAHs found could be an indication of the forest composition during the fire event. These added elements could provide further information on biomass burning and composition. Laboratory experiments, including burning material that is typically found in the boreal forest, would be useful to help determine which different types of PAHs and their concentrations would be expected as a result of fires on the landscape. Laboratory experiments could also be designed to examine how fire temperature impacts PAH release.

4.3 – Implications

The magnitude and frequency of wildfire is highly variable both spatially and temporally. In addition, historical records of past fire activity are temporally short, especially for Yukon where remotely-sensed data only extends back until AD 1946. Paleo-fire records can provide a longer record to investigate the relationship between fire, climate and vegetation, however these long-term fire records are lacking in Yukon. This is problematic as FRIs go beyond the modern record, meaning fire managers cannot accurately assess the historical fire regime for an area or use the historical record to predict risk under current or future conditions. Also, there are often large gaps in datasets for when the last fire occurred in a particular region, making it harder to assess the level of risk. For example, many fires have been recorded in the Southern Lakes ecoregion from 1946 until present, including fires in 1947, 1948, 1951, 1958, 1960, 1991, 1998 and 2003. However, none of these records were located within the Spindly Pine Lake region. Therefore, this study relied on fire scars from a dendrochronology analysis (Robillard, 2012) to determine the previous fire at this location. This showed that the last known fire occurred in 1892 AD, 125 years ago and results from the macroscopic charcoal analysis showed that for the past ~2000 years the mFRI is 88 years. The knowledge gained from combining the dendrochronology and charcoal analysis shows the Spindly Pine Lake region is overdue for a large burn based on the recent and long-term fire history in the area. This kind of information is only available by looking beyond the remotely-sensed data, and can be useful for forest managers and stakeholders in accurately assessing risk by providing information on forest characteristics such as age and species for an area where the most recent fire and long-term fire history is unknown. However, these long-term fire records are currently lacking from the current fire prediction and preparedness in Yukon. Thus, presenting a need to have the resources necessary to effectively anticipate the occurrence of fire in an area. The current preparedness system uses an analysis of historic risk and daily fire danger levels from several preparedness documents, as well as the Canadian Fire Behaviour Prediction System (Yukon Wildland Fire Management, 2005). However, including long-term fire histories can increase the accuracy of risk assessment by adding knowledge of the previous fire regime as well as mFRIs.

Results of this study show that the current conditions at Spindly Pine Lake are comparable to that of pollen Zone 4, particularly at ~1000 yr BP. During this time the vegetation was dominated by lodgepole pine, the AL was in a strong, easterly position and temperatures were warming as a result of the Medieval Climate Anomaly. This resulted in a shift in the fire regime to the most active period, in terms of fire frequency, throughout the Holocene. The FRIs shortened to ~70 to 80 years and there were numerous instances when multiple fires occurred within a century. Currently, the vegetation is dominated by lodgepole pine, the AL shows a prolonged strong, easterly position and temperatures are warming as a result of climate change. Therefore, this period at ~1000 yr BP may provide fire managers some insight on how the fire regime may look in the coming years. During this time there were multiple instances where there was as little as 20 to 30 years between fires, which would present a drastic shift from the current fire regime. This would also result in an increased risk in terms of both health impacts from decreased air quality associated with wildfire, as well as threat of property damage.

The Yukon Wildland Fire Management (2005) found that communication was an issue with the First Nations. First Nations do not have the resources necessary to monitor fire and its impacts, therefore effective communication systems are needed regarding fire location. Long-term fire studies can provide an early warning system for forests that may be at higher risk for a fire, based on the last fire in that location and mFRIs. This may be a useful tool in prediction that provides an early warning when the resources are lacking to access the online risk maps.

Over the 20^{th} century, fire activity was often impacted by fire suppression efforts as wildfire was viewed solely as a threat to life, property and resources, while the natural ecological benefits were less understood. In some areas this has resulted in a shift in the fire regime outside the natural range of variability. Results from this study indicate fire suppression efforts have impacted the fire regime in the Spindly Pine Lake region. The last fire in the area occurred in ~AD 1892, 125 years ago. Meanwhile the mFRI for a pine-dominated forest in this area is ~88 years, suggesting the area has shifted outside of the natural range of variability. This is important because a lack of fire activity leads to a build up of fuels, resulting in a high-severity fire. The city of Whitehorse has recently started using controlled burns as a new approach to fuel management. In 2017 they started a pilot project where they used controlled burns along roadways to reduce fuel build up, deeming it a cost effective approach. This type of approach is useful in reducing the build up of fuels, and introducing fire back into the ecosystem where it has otherwise been suppressed for many years. Moving forward a shift in fire management may be necessary, moving away from fire suppression while implementing more controlled burns. Controlled burns should be viewed and communicated positively, however this may require education through the FireSmart initiative, focusing on all the positive ecological benefits fire has as a natural part of the forest ecosystem.

In addition to daily weather and long term climate data, forest characteristics such as age and composition need to be considered for better risk assessments. Forests with longer FRIs, or older forests, need to be considered as areas with greater risk of a future fire. In addition to age, composition is also important as forest dominated by lodgepole pine may burn more frequently than white spruce forests. Based on this study, it may be beneficial to target forests surrounding Whitehorse, and other regions, where the forest is predominantly lodgepole pine and over 80 years old as areas to implement controlled burns. These forests may be more susceptible to a future burn and thus present a higher risk. Introducing fire to these forests as they approach the age where they typically burn, based on the mFRI, may be a way to reduce fuel load, possibility reset the FRI and prevent the massive, high severity type fire that causes significant damage. However, this is only made possible by knowing the mFRI for a region based on long term data from macroscopic charcoal studies, as well as the age of the current forests.

REFERENCES

Flannigan, M. D., Logan, K. A., Amiro, B. D., Skinner, W. R., & Stocks, B. J. (2005). Future area burned in Canada. *Climatic change*, 72(1), 1-16.

Hawthorne, D., Mustaphi, C. J. C., Aleman, J. C., Blarquez, O., Colombaroli, D., Daniau, A. L., Marlon, J.R., Power, M., Vanniere, B., Han, Y. and Hantson, S. (2017). Global Modern Charcoal Dataset (GMCD): A tool for exploring proxy-fire linkages and spatial patterns of biomass burning. *Quaternary International*.

National Research Council (US). Committee on Pyrene, & Selected Analogues. (1983). Polycyclic aromatic hydrocarbons: evaluation of sources and effects. National Academies Press.

NTP (National Toxicology Program). 2016. Report on Carcinogens, Fourteenth Edition.; Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service.

Pisaric, M. (2006). Personal communication. Professor, Department of Geography and Tourism Studies, Brock University.

Robillard, K. (2012). A 250-year record of forest fire history in Canada's southwestern Yukon. Unpublished undergraduate thesis. Department of Geography and Environmental Studies, Carleton University, Ottawa, ON, Canada.

Spracklen, D. V., Mickley, L. J., Logan, J. A., Hudman, R. C., Yevich, R., Flannigan, M. D., & Westerling, A. L. (2009). Impacts of climate change from 2000 to 2050 on wildfire activity and carbonaceous aerosol concentrations in the western United States. *Journal of Geophysical Research: Atmospheres*, 114(D20).

Stocks, B. J., Fosberg, M. A., Lynham, T. J., Mearns, L., Wotton, B. M., Yang, Q., Jin, J.Z., Lawrence, K, Hartley, G.R., Mason, J.A & McKenney, D. W. (1998). Climate change and forest fire potential in Russian and Canadian boreal forests. *Climatic Change*, 38(1), 1-13.

Yukon Wildland Fire Management. (2005). *2004 Wildland Fire Review: Final Report.* Whitehorse: Yukon Wildland Fire Management.

APPENDIX ONE

METHODS

Macroscopic Charcoal

Contiguous subsamples were measured at $1cm^3$ and were placed in a deflocculating solution overnight (Fig. 4.1). This solution contained 30 ml of distilled water mixed with Sparkleen® to disaggregate the sediment and 10 ml of 3% hydrogen peroxide to bleach any organic material, in order to help distinguish charcoal from organics. After soaking overnight the solution was carefully washed through a 150µm mesh sieve using distilled water. The remaining material was then washed into a gridded petri dish to be counted under a microscope for total number of charcoal pieces per $1cm^3$. Manipulating the charcoal pieces with a metal probe under the microscope was useful for correct identification. Charcoal was identified as black, opaque, angular and typically planar fragments (Whitlock and Larsen, 2001).

The bCHAR and C_{Peak} parameters were chosen based on existing literature (Cleveland, 1976; Gavin et al., 2006 & Higuera et al., 2010) suggesting they are the best models to not only eliminate bias and variability between models within a charcoal study, but also across studies (Higuera et al, 2010). Higuera et al. (2010) suggest that choosing a locally defined model will reduce the amount of variability between models in a charcoal study, and the NR model is the simplest and typically the most appropriate. Also, the index model was not applicable in this study as there were values of 0 throughout the record in the bCHAR. This does not work mathematically because the index model is a ratio where bCHAR is the denominator (CHAR ÷ bCHAR), therefore the residual model was chosen. Applying these local parameters will allow for more accurate charcoal studies, as well as the ability to compare results from different studies around the world with the increased accuracy and consistency in the detrending process (Higuera et al., 2010). The robust LOWESS smoother (Figure 4.2) was chosen for the bCHAR as it should be robust to outliers (Cleveland, 1979), and a window of 500 years was applied as it is narrow enough to capture the centennial-scale variation in CHAR, but wide enough to not be effected by large peaks (Gavin et al., 2006).

A second model was run in CharAnalysis to address any concern of bias in the record due to changing sedimentation rates. As seen by the age-depth model, sedimentation rates change throughout this record with low sedimentation in the early Holocene portion of the record and higher sedimentation rates during the last ~1000 years. As a result of the increase in sedimentation rates, the resolution also increased, potentially creating a bias towards higher fire frequency as the higher resolution may produce more peaks. Therefore, sedimentation rates were standardized before the second model was run in CharAnalysis to test for any potential bias. This was done by averaging multiple 0.5cm interval charcoal counts. During the late Holocene (0-1000 yr BP), where sedimentation rates were 6-7 years per 0.5cm, 3 samples were combined and average. During the middle Holocene (1000-6000 yr BP), sedimentation rates were ~10 years per 0.5cm, therefore 2 samples were combined and average. Finally, during the early Holocene (6000-12449 yr BP) no adjustments were applied as every 0.5cm interval represented ~20 years. Results of this model were very similar to the initial model. The trends in fire frequency were comparable as all the major changes resulting from the top-down and bottom-up controls were still detected. However, during the late Holocene some of the peaks had decreased in magnitude as a result of averaging multiple 0.5 cm intervals. The initial model was used for all analyses since the results of the second model were not considerably different and no bias was detected. The initial model interpolated the record to constant temporal resolution of 10-years, which is an important step to account for unequal sampling intervals as a result of changing sedimentation rates (Higuera, 2010).

The SNI is a way to quantify the separation between the large peaks and the slowly varying background noise. Kelly et al. (2010) suggest that a charcoal record with a SNI > 3 is suitable for peak detection analysis. However, it is important to note that the SNI does not validate that the peaks are a result of a fire, but that the record itself is suitable for peak detection analysis. Therefore, a record with a SNI > 3 still has the potential for peaks to be a result of other factors such as large erosion events for example. Also, a record with a SNI < 3 is not suggesting that fires are not present in the record, rather they are not detectable using peak analysis as the peaks are not distinguishable from the slowly varying background noise (Kelly et al. 2010). This reinforces the importance of quality site selection to ensure primary charcoal is maximized and secondary charcoal influx is minimized.

Figure 4.1 – Charcoal samples soaking overnight in the deflocculant solution to later be sieved. Samples in the back of the fume hood have already been sieved and counted.

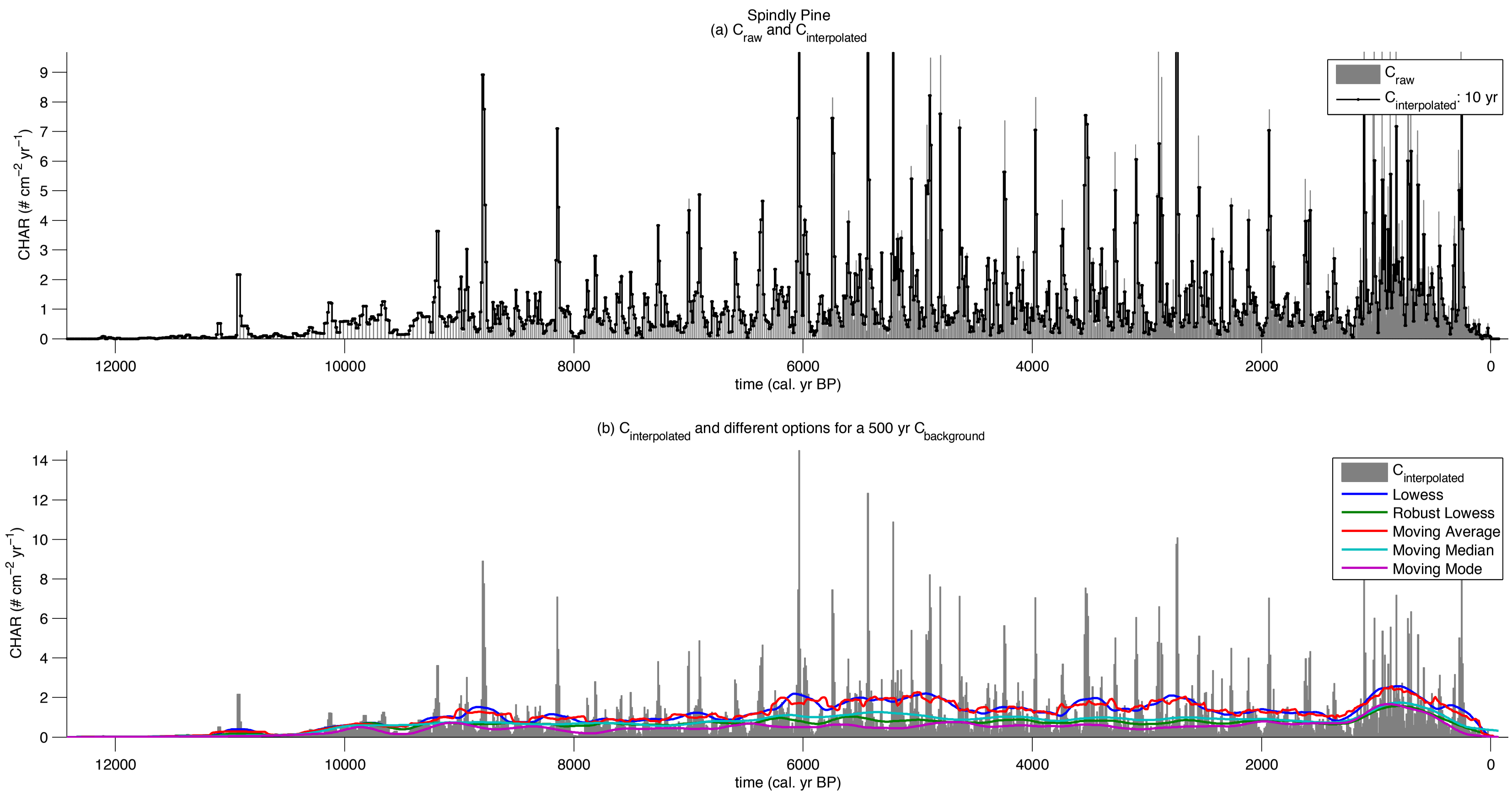


Figure 4.2 – a) raw charcoal concentration $cm^{-2}yr^{-1}$ b) 5 different threshold options for determining 500-year background charcoal. The robust LOWESS filter was chosen, representing by the dark green line.

Loss-On-Ignition

Subsamples of 1 cm^3 where measured out, placed in a crucible and weighed to find the initial wet weight (W_{Wet}) of the sample. These samples were then placed in a drying oven overnight (requires 12-24 hours) at a temperature of 110°C to remove the water from the sediment. The following day the samples were allowed to cool gradually in a desiccator for 30 minutes to ensure atmospheric water content did not alter the dried weights. After cooling, the samples were weighed again to calculate dry weight (DW_{110}). Weight loss after drying represents the water content of the sample. The samples were then placed in a programmable muffle furnace at a temperature of 550°C for 4 hours. The samples were placed in the desiccator for 30 minutes to cool and were weighed again (DW_{550}). The weight loss after burning at 550°C represents the organic content of the sediment. Finally, the samples were returned to the muffle furnace at a temperature of 950°C for 2 hours. After cooling in the desiccator they were weighed one last time (DW_{950}). The weight loss at this stage represents the carbonate content in the sediment and any remaining material represents the silicilastic material. For all measurements a scale with the precision of 0.001g was used. The equations used to calculate LOI values are below:

1) Water content % = $((Wwet - DW_{110})/(Wwet))(100)$

2) Organic content % = $((DW_{110} – DW_{550}))/DW_{110}))(100)$

3) Carbonate content % = $((DW_{550} – DW_{950})/DW_{110}))(1.36)(100)$

Dendrochronology

Tree cores were collected from lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*) trees using a Haglof increment borer with an internal diameter of 4.3 mm (Figure 4.3). The 22 tree core samples were prepared using standard dendrochronological methods from Stokes and Smiley (1968). After carefully removing the cores from the straws, the site and sample number were recorded and then samples were sanded and mounted on wood slates for analysis. The sanding was done by hand starting with 80-grit sandpaper followed by progressively finer grit up to 400-grit. Samples were sanded so the surface was polished and all rings were visible. Tree cores were mounted to wood core holders with carpenters glue and tied with string to hold the cores in place until they were dry. Growth characteristics were not of interest to this study, therefore rings were cross dated and counted in order to determine the current age of the canopy surrounding the lake. This helps provide information on when the last fire occurred in the catchment by comparing the establishment ages to fire scars collected at nearby sites and the most recent peak in the sedimentary charcoal.

Figure 2.5 shows the current extent of the documented fire history throughout Yukon Territory from 1946 to 2015. The fire year and size can be seen in Table 2.2. Results show multiple fires occurring in 1948, 1958 and 1998, with the largest fire in 1958 burning 126,903 ha of land. However, none of these fires occurred in the vicinity of Spindly Pine Lake or its catchment and therefore are not expected to result in a peak in the charcoal record from this lake. As a result, fire scars and stand establishment data based on dendrochronological samples from the area around Spindly Pine Lake will be relied upon for the most recent fires in this region.

Figure 4.3 – Photograph of researcher coring a lodgepole pine tree using a Haglof increment borer.

Bacon Model

Bacon breaks the core into many vertical sections to apply the MCMC simulations. This was set to res = 50 (50cm thickness), an increase from the default settings, which is suggested for cores longer than a few meters (Blaauw and Christen, 2013). The accumulation mean (acc.mean) was increased to 50 from the default of acc.mean = 20, this was to account for the slower sedimentation rates at the bottom of the core. Calculating sedimentation rates for every cm on long cores (over 500 cm) can take a long time to process; accordingly Bacon offers alternate intervals (d.by) that require less time. However, sedimentation rates were needed every 0.5 cm for the macroscopic charcoal analysis, therefore d.by was set to 0.5 and the alternate interval prompt was denied. This provides the necessary sedimentation rates every 0.5cm, with each trial averaging ~30 minutes in processing time. The Bacon default depth for maximum calculation (maxcalc) is 500 cm, which had to be extended to maxcalc = 539.5 as the core was longer than 500 cm. All other parameters were kept at their default values.

Several models were developed using Bacon v2.2. After reviewing the models, one of the bulk sediment dates (UOC – 3591) was omitted from the age-depth model. While the date fit chronologically with the other dates, its inclusion in the age-depth model resulted in a rapid change in sedimentation. However, observation of the sediment core itself did not suggest a rapid change in sedimentation had occurred (i.e., no visible change in sediment texture or other discernable indicators). A radiocarbon date from a piece of charcoal recovered from the core at 492.5 cm fit the model well and suggested that the bulk sediment sample was an incorrect age, potentially from old age offset. Although the old age offset was adjusted for using the calibrated sample from the tephra layer, the amount of offset can change over time. Therefore, it was assumed that this sample varied too much from the calibrated sample and it was consequently omitted from the model.

Field Methods

Figure 4.4 – Photograph showing the collection of the surficial core using the Maxi-Glew corer from the floating platform.

Figure 4.5 – Photograph of the surficial sediment core being extruded in the field and stored in Whirl Pak bags.

APPENDIX TWO

CORE ALIGNMENT

Surficial and Piston core alignment

The overlap between the piston and gravity cores was determined primarily via the macroscopic charcoal data (Figure 4.6).

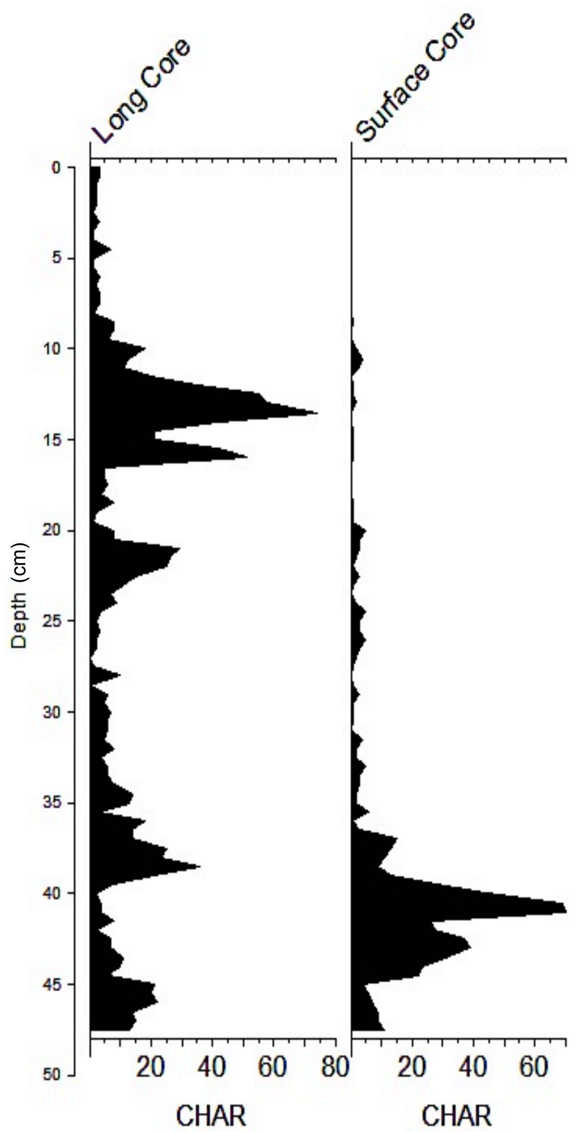


Figure 4.6– Macroscopic charcoal in CHAR (pieces per cm^2 per year) for both sediment cores. The overlap was found at 0cm (piston core) and 27.5 (surface core).

The sediment core chronology is based on a series of ^{14}C dates and the accepted age of the WRA tephra layer (Figure 3.4). With this record spanning over 12 500 years, ^{210}Pb dates were not used as they would only represent a small fraction of the record. It was determined that opting for additional ^{14}C dates over the ^{210}Pb dates would be more useful to develop an accurate model throughout the entire record.

To adjust for the freshwater reservoir effect, a bulk sample (UOC – 3173) was dated directly after the WRA layer, which has a known date of deposition of 1147 yr BP. UOC – 3173 was dated at 1702 ^{14}C yr BP or 1625 cal yr BP. Therefore, after calibration, the old age offset from the reservoir effect was estimated at 478 years. This was then applied to all the bulk sediment samples to adjust for old age offset (Patterson et al., 2017). The adjustment was made after calibration, as the varying atmospheric ^{14}C levels over time would skew the adjustment value if it were applied before calibration. It is important to note that the old age offset will not be consistent throughout the record, and therefore sample UOC – 3591 was omitted, as the age did not fit the Bacon model. It is assumed that this old age offset differs from the 478 year offset, which is supported by a nearby (11cm apart) charcoal date that accurately fit the model. Considering these two factors it was felt that UOC – 3591 could be safely omitted from the model.

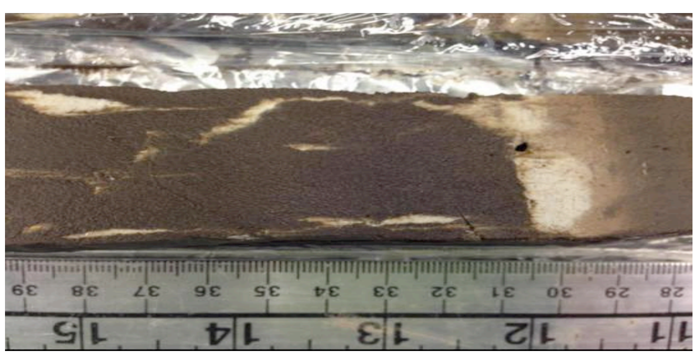


Figure 4.7 – Photograph of the long core retrieved with the Livingston piston core, showing the presence of the White River Ash deposit.

APPENDIX THREE

RAW DATA

Table I – Charcoal and morphotype total counts for Spindly Pine Lake sediment core. Top and bottom depth as well as top and bottom age are also indicated.

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
0.0	0.5	-66	-61	1	0											
0.5	1.0	-61	-57	1	0											
1.0	1.5	-57	-52	1	0											
1.5	2.0	-52	-47	1	0											
2.0	2.5	-47	-42	1	0											
2.5	3.0	-42	-37	1	0											
3.0	3.5	-37	-33	1	0											
3.5	4.0	-33	-28	1	0											
4.0	4.5	-28	-23	1	0											
4.5	5.0	-23	-18	1	0											
5.0	5.5	-18	-15	1	0											
5.5	6.0	-15	-11	1	0											
6.0	6.5	-11	-7	1	0											
6.5	7.0	-7	-3	1	0											
7.0	7.5	-3	1	1	0											
7.5	8.0	1	5	1	0											
8.0	8.5	5	9	1	0											
8.5	9.0	9	13	1	1		1									
9.0	9.5	13	17	1	0											
9.5	10.0	17	20	1	0											
10.0	10.5	20	24	1	2		1	1								

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
10.5	11.0	24	28	1	4		2	2								
11.0	11.5	28	32	1	3		2	1								
11.5	12.0	32	36	1	0											
12.0	12.5	36	39	1	1		1									
12.5	13.0	39	43	1	1		1									
13.0	13.5	43	47	1	2		1	1								
13.5	14.0	47	51	1	0											
14.0	14.5	51	55	1	0											
14.5	15.0	55	58	1	1		1									
15.0	15.5	58	63	1	1		1									
15.5	16.0	63	68	1	1			1								
16.0	16.5	68	72	1	1			1								
16.5	17.0	72	77	1	0											
17.0	17.5	77	81	1	0											
17.5	18.0	81	86	1	0											
18.0	18.5	86	90	1	0											
18.5	19.0	90	95	1	1		1									
19.0	19.5	95	99	1	1			1								
19.5	20.0	99	104	1	1			1								
20.0	20.5	104	107	1	5		2	2			1					
20.5	21.0	107	111	1	3		1	1			1					
21.0	21.5	111	115	1	3		1	1			1					
21.5	22.0	115	119	1	2		1	1								
22.0	22.5	119	123	1	1		1									
22.5	23.0	123	127	1	3		1	2								
23.0	23.5	127	131	1	1			1								
23.5	24.0	131	135	1	0											

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
24.0	24.5	135	138	1	2		1	1								
24.5	25.0	138	142	1	5		2	2			1					
25.0	25.5	142	146	1	3		1	2								
25.5	26.0	146	150	1	3		2	1								
26.0	26.5	150	154	1	5		2	2			1					
26.5	27.0	154	158	1	3		1	1								
27.0	27.5	158	161	1	2		1	1								
27.5	28.0	161	165	1	3			3								
28.0	28.5	165	169	1	3		1	2								
28.5	29.0	169	173	1	2		1	1								
29.0	29.5	173	177	1	2			2								
29.5	30.0	177	181	1	2			2								
30.0	30.5	181	184	1	1			1								
30.5	31.0	184	187	1	3			1			1		1			
31.0	31.5	187	190	1	1			1								
31.5	32.0	190	194	1	1			1								
32.0	32.5	194	197	1	7			6			1					
32.5	33.0	197	200	1	1								1			
33.0	33.5	200	203	1	1			1								
33.5	34.0	203	206	1	3			2		1						
34.0	34.5	206	210	1	2			2								
34.5	35.0	210	213	1	3			2			1					
35.0	35.5	213	217	1	3		1	1			1					
35.5	36.0	217	221	1	1			1								
36.0	36.5	221	225	1	8			6			2					
36.5	37.0	225	229	1	8			6			1					
37.0	37.5	229	233	1	6			3			3					

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
37.5	38.0	233	237	1	18		2	8			6		1	1		
38.0	38.5	237	241	1	13		2	4			7					
38.5	39.0	241	245	1	11		1	5			4		1			
39.0	39.5	245	249	1	20		6	8			3		2			
39.5	40.0	249	253	1	35		5	17			12		1			
40.0	40.5	253	257	1	55		6	28			18		2	1		
40.5	41.0	257	261	1	58		12	24			17		5			
41.0	41.5	261	265	1	74		6	30		1	21		15			
41.5	42.0	265	269	1	42		7	17			12		6			
42.0	42.5	269	273	1	21			11			6		3			
42.5	43.0	273	277	1	21		3	9			6		3			
43.0	43.5	277	281	1	42		10	19			12		1			
43.5	44.0	281	285	1	51		5	13			24		7	2		
44.0	44.5	285	289	1	5			4			1					
44.5	45.0	289	292	1	5		1	4								
45.0	45.5	292	296	1	6		1	3			2					
45.5	46.0	296	299	1	4			4								
46.0	46.5	299	303	1	8			5			2	1				
46.5	47.0	303	306	1	2			2								
47.0	47.5	306	310	1	1			1								
47.5	48.0	310	313	1	8		1	5					2			
48.0	48.5	313	317	1	8		2	3			2		1			
48.5	49.0	317	320	1	29		7	15			5		2			
49.0	49.5	320	324	1	26		3	8			7		4	4		
49.5	50.0	324	327	1	25		3	8			9		5			
50.0	50.5	327	331	1	15		1	5			6		2	1		
50.5	51.0	331	334	1	11			7			3		1			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
51.0	51.5	334	338	1	7		1	3			3					
51.5	52.0	338	341	1	9		1	4			3					
52.0	52.5	341	345	1	4			3			1					
52.5	53.0	345	348	1	2						1		1			
53.0	53.5	348	352	1	3			2			1					
53.5	54.0	352	355	1	2		1				1					
54.0	54.5	355	359	1	2			1			1					
54.5	55.0	359	362	1	0											
55.0	55.5	362	367	1	1			1								
55.5	56.0	367	371	1	10		1	4			4		1			
56.0	56.5	371	376	1	0											
56.5	57.0	376	380	1	6		1	4			1					
57.0	57.5	380	385	1	5			4			1					
57.5	58.0	385	389	1	7		2	4					1			
58.0	58.5	389	394	1	6			1			1		4			
58.5	59.0	394	398	1	6		1	4			1					
59.0	59.5	398	403	1	5			3			1		1			
59.5	60.0	403	407	1	8			4			1		2	1		
60.0	60.5	407	411	1	4			4								
60.5	61.0	411	414	1	6			4			2					
61.0	61.5	414	418	1	6		1	5								
61.5	62.0	418	422	1	8		1	3			2		2			
62.0	62.5	422	426	1	14		4	7			3					
62.5	63.0	426	429	1	13			7			4		1			
63.0	63.5	429	433	1	3			1					2			
63.5	64.0	433	437	1	18		5	6			3		2			
64.0	64.5	437	440	1	14		4	7			2					

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
64.5	65.0	440	444	1	14		2	9			3					
65.0	65.5	444	448	1	25		2	13			7		1			
65.5	66.0	448	452	1	23		3	9			8		2			
66.0	66.5	452	457	1	36		3	19			9		5			
66.5	67.0	457	461	1	21		4	10			6		1			
67.0	67.5	461	465	1	8			5			3					
67.5	68.0	465	469	1	2						2					
68.0	68.5	469	473	1	4			3			1					
68.5	69.0	473	478	1	4		1				2		1			
69.0	69.5	478	482	1	8		2	4			2					
69.5	70.0	482	486	1	2		1	1								
70.0	70.5	486	491	1	7		1	3			3					
70.5	71.0	491	495	1	7		1	4			1		1			
71.0	71.5	495	499	1	11		2	4			3		2			
71.5	72.0	499	504	1	10		1	5			2		2			
72.0	72.5	504	508	1	6		1	5								
72.5	73.0	508	512	1	21		1	8			11		1			
73.0	73.5	512	517	1	20		3	10			6		1			
73.5	74.0	517	521	1	22		4	8			9		1			
74.0	74.5	521	525	1	14			12			2					
74.5	75.0	525	530	1	15		4	6			5					
75.0	75.5	530	533	1	13		1	6			5		1			
75.5	76.0	533	537	1	10			9			1					
76.0	76.5	537	540	1	7			5			2					
76.5	77.0	540	544	1	14		2	6			4		2			
77.0	77.5	544	547	1	17		2	7			7			1		
77.5	78.0	547	551	1	9		1				5		3			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
78.0	78.5	551	555	1	5			4			1					
78.5	79.0	555	558	1	6			2			2		2			
79.0	79.5	558	562	1	6			1			3		2			
79.5	80.0	562	565	1	6		2	2			1		1			
80.0	80.5	565	568	1	2			2								
80.5	81.0	568	571	1	3			1					2			
81.0	81.5	571	574	1	6			1			2		3			
81.5	82.0	574	577	1	4			2			1		1			
82.0	82.5	577	580	1	4			3			1					
82.5	83.0	580	583	1	9		1	6			1		1			
83.0	83.5	583	586	1	19		3	7			5		4			
83.5	84.0	586	589	1	29		5	12			7		5			
84.0	84.5	589	592	1	14			7			7					
84.5	85.0	592	595	1	21		3	4			8		6			
85.0	85.5	595	599	1	7			6			1					
85.5	86.0	599	603	1	10		1	5			1		3			
86.0	86.5	603	607	1	18		3	5			7		3			
86.5	87.0	607	611	1	13		4	8			1					
87.0	87.5	611	614	1	13		1	5			4		3			
87.5	88.0	614	618	1	12		2	5			5					
88.0	88.5	618	622	1	18		5	8			4		1			
88.5	89.0	622	626	1	12		3	7			1		1			
89.0	89.5	626	630	1	11		4	3			2		2			
89.5	90.0	630	634	1	10		2	6					2			
90.0	90.5	634	638	1	20		1	5			10		4			
90.5	91.0	638	641	1	52		5	18			15		14			
91.0	91.5	641	645	1	46		5	14		1	16		10			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
91.5	92.0	645	649	1	13			8			3		2			
92.0	92.5	649	653	1	8			4			3		1			
92.5	93.0	653	656	1	2			1			1					
93.0	93.5	656	660	1	7			7								
93.5	94.0	660	664	1	14			6			7		1			
94.0	94.5	664	667	1	8		1	5			1		1			
94.5	95.0	667	671	1	13		2	9					2			
95.0	95.5	671	676	1	6		1	4					1			
95.5	96.0	676	680	1	7			5			1		1			
96.0	96.5	680	684	1	3			1			2					
96.5	97.0	684	689	1	12		1	9					2			
97.0	97.5	689	693	1	13		3	6			2		2			
97.5	98.0	693	697	1	34		6	12			13		3			
98.0	98.5	697	702	1	82		19	15			29		19			
98.5	99.0	702	706	1	32		6	9			11		6			
99.0	99.5	706	710	1	14			7			5		2			
99.5	100.0	710	715	1	14		1	7			3		3			
100.0	100.5	715	719	1	17		4	7			5		1			
100.5	101.0	719	723	1	63		13	13			20		17			
101.0	101.5	723	727	1	68		2	13			34		18	1		
101.5	102.0	727	731	1	38		10	10			18					
102.0	102.5	731	735	1	43		27	5			6		5			
102.5	103.0	735	738	1	6			4			2					
103.0	103.5	738	742	1	11		4	3			3		1			
103.5	104.0	742	746	1	2			1			1					
104.0	104.5	746	750	1	3			2			1					
104.5	105.0	750	754	1	5			4					1			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
105.0	105.5	754	759	1	3		2				1					
105.5	106.0	759	763	1	11		2	4			3		2			
106.0	106.5	763	768	1	9		1	5			3					
106.5	107.0	768	772	1	17		2	8			3		4			
107.0	107.5	772	777	1	36		8	12			9		7			
107.5	108.0	777	781	1	20		1	7			6		4	2		
108.0	108.5	781	786	1	22		3	8			9		1			
108.5	109.0	786	790	1	16		4	9					3			
109.0	109.5	790	795	1	7		2	2			3					
109.5	110.0	795	799	1	13		2	7			4					
110.0	110.5	799	803	1	15		2	9			3		1			
110.5	111.0	803	806	1	28		2	13			6		7			
111.0	111.5	806	810	1	17		5	6			3		3			
111.5	112.0	810	814	1	15			12			3					
112.0	112.5	814	817	1	19		7	7			4		1			
112.5	113.0	817	821	1	17			7			8		2			
113.0	113.5	821	824	1	11		2	4			4		1			
113.5	114.0	824	828	1	46		8	15			17		6			
114.0	114.5	828	831	1	83		12	33			22		14	2		
114.5	115.0	831	835	1	20		3	7			3		7			
115.0	115.5	835	839	1	15		2	4			5		4			
115.5	116.0	839	842	1	12		2	8			2					
116.0	116.5	842	846	1	13			6			6		1			
116.5	117.0	846	849	1	17		2	6			8		1			
117.0	117.5	849	853	1	23		3	12			6		1			
117.5	118.0	853	857	1	11			6			2		3			
118.0	118.5	857	860	1	16		2	8			3		3			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
118.5	119.0	860	864	1	7			4			3					
119.0	119.5	864	867	1	7		1	3			2		1			
119.5	120.0	867	871	1	5		1	3					1			
120.0	120.5	871	875	1	11		1	8			2					
120.5	121.0	875	878	1	23		3	9			6		5			
121.0	121.5	878	882	1	82		4	32			35		11			
121.5	122.0	882	886	1	8		1	4			2		1			
122.0	122.5	886	890	1	14			6			5		3			
122.5	123.0	890	893	1	10		2	7					1			
123.0	123.5	893	897	1	19		2	9			5		3			
123.5	124.0	897	901	1	39		6	16			11		5		1	
124.0	124.5	901	904	1	22		5	7			7		3			
124.5	125.0	904	908	1	11		1	6			3		1			
125.0	125.5	908	912	1	4			3					1			
125.5	126.0	912	915	1	5		1	3					1			
126.0	126.5	915	919	1	6			6								
126.5	127.0	919	923	1	19		5	10			3		1			
127.0	127.5	923	926	1	14		3	10					1			
127.5	128.0	926	930	1	23		5	9			6		3			
128.0	128.5	930	933	1	48		8	18			12		9			
128.5	129.0	933	937	1	19		2	8			6		3			
129.0	129.5	937	941	1	21		2	4			9		6			
129.5	130.0	941	944	1	11		2	4			4		1			
130.0	130.5	944	947	1	19		4	9			5		1			
130.5	131.0	947	950	1	15			7			5		3			
131.0	131.5	950	953	1	63		12	23			21		7			
131.5	132.0	953	956	1	19		1	7			4		7			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
132.0	132.5	956	959	1	5			2			2		1			
132.5	133.0	959	962	1	8			7			1					
133.0	133.5	962	964	1	15		1	6			6		2			
133.5	134.0	964	967	1	8			6			2					
134.0	134.5	967	970	1	8			3			4		1			
134.5	135.0	970	973	1	16		5	5			6					
135.0	135.5	973	977	1	18		1	4			10		3			
135.5	136.0	977	980	1	4			3			1					
136.0	136.5	980	983	1	2						1		1			
136.5	137.0	983	987	1	2			1			1					
137.0	137.5	987	990	1	0											
137.5	138.0	990	994	1	2			2								
138.0	138.5	994	997	1	4			1					3			
138.5	139.0	997	1001	1	11			5			5		1			
139.0	139.5	1001	1004	1	10		2	1			4		3			
139.5	140.0	1004	1008	1	9			5			4					
140.0	140.5	1008	1010	1	20			8			6		6			
140.5	141.0	1010	1013	1	9			6			3					
141.0	141.5	1013	1016	1	19			10			6		3			
141.5	142.0	1016	1019	1	64		5	23		1	18		15			
142.0	142.5	1019	1022	1	36		6	14			10		5			
142.5	143.0	1022	1025	1	12		2	8			2					
143.0	143.5	1025	1028	1	3			3								
143.5	144.0	1028	1031	1	55		11	23			16		5			
144.0	144.5	1031	1034	1	15			6			6		3			
144.5	145.0	1034	1037	1	28		3	11			8		6			
145.0	145.5	1037	1041	1	5			2			1		2			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm³)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
145.5	146.0	1041	1046	1	4			2			1		1			
146.0	146.5	1046	1050	1	13		1	7			2		3			
146.5	147.0	1050	1054	1	9		1	2			3		3			
147.0	147.5	1054	1058	1	8		2	3			3					
147.5	148.0	1058	1063	1	7		2	4			1					
148.0	148.5	1063	1067	1	9		2	4			2		1			
148.5	149.0	1067	1071	1	4		2	2								
149.0	149.5	1071	1075	1	11		3	5			2		1			
149.5	150.0	1075	1080	1	7		2	3			1		1			
150.0	150.5	1080	1083	1	20		3	9			4		4			
150.5	151.0	1083	1087	1	20		3	7			4		5	1		
151.0	151.5	1087	1091	1	6			3			2		1			
151.5	152.0	1091	1095	1	3			1			2					
152.0	152.5	1095	1098	1	40		12	20		2	4		1			1
152.5	153.0	1098	1102	1	30		10	12			5		3			
153.0	153.5	1102	1106	1	30		9	15			5		1			
153.5	154.0	1106	1110	1	122		33	48			22		18	1		
154.0	154.5	1110	1114	1	42		5	10			15		12			
154.5	155.0	1114	1117	1	6		1	2			2		1			
155.0	155.5	1117	1122	1	5		1	2			1		1			
155.5	156.0	1122	1127	1	9			3			4		2			
156.0	156.5	1127	1132	1	4			1			3					
156.5	157.0	1132	1137	1	0											
157.0	157.5	1137	1142	1	30		4	7			10		9			
157.5	158.0	1142	1146	1	17		2	10			4		1			
158.0	158.5	1146	1151	1	5		1				3		1			
158.5	159.0	1151	1156	1	2			2								

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
159.0	159.5	1156	1161	1	11			5			5		1			
159.5	160.0	1161	1166	1	17		2	6			3		4	2		
160.0	160.5	1166	1176	1	24		2	6			12		4			
160.5	161.0	1176	1185	1	18		2	4		1	3		7	1		
161.0	161.5	1185	1194	1	13		3	3		1	4		2			
161.5	162.0	1194	1204	1	8		1	2			2		3			
162.0	162.5	1204	1213	1	1						1					
162.5	163.0	1213	1222	1	1						1					
163.0	163.5	1222	1232	1	9		1	5			1		2			
163.5	164.0	1232	1241	1	7		1	3			2		1			
164.0	164.5	1241	1251	1	16		4	8			2		2			
164.5	165.0	1251	1260	1	21		2	11			6		2			
165.0	165.5	1260	1269	1	5			3			1		1			
165.5	166.0	1269	1278	1	4			1			3					
166.0	166.5	1278	1287	1	3			3								
166.5	167.0	1287	1296	1	7			5			2					
167.0	167.5	1296	1306	1	6		2	1			3					
167.5	168.0	1306	1315	1	11		1	6			2		2			
168.0	168.5	1315	1324	1	13		2	6					5			
168.5	169.0	1324	1333	1	11		2	3			5		1			
169.0	169.5	1333	1342	1	9		2	7								
169.5	170.0	1342	1351	1	14		4	9					1			
170.0	170.5	1351	1361	1	30		11	13			3		3			
170.5	171.0	1361	1371	1	49		21	17			9		2			
171.0	171.5	1371	1380	1	59		18	25			10		6			
171.5	172.0	1380	1390	1	19		3	9			2		5			
172.0	172.5	1390	1399	1	10			7			1		2			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
172.5	173.0	1399	1409	1	15		6	5			3		1			
173.0	173.5	1409	1418	1	9			5			3		1			
173.5	174.0	1418	1428	1	40		7	15			10		8			
174.0	174.5	1428	1437	1	24		6	9			7		2			
174.5	175.0	1437	1446	1	5			4			1					
175.0	175.5	1446	1456	1	7			5			1		1			
175.5	176.0	1456	1465	1	8			8								
176.0	176.5	1465	1475	1	18		2	5			10		1			
176.5	177.0	1475	1484	1	15		1	4			5		5			
177.0	177.5	1484	1493	1	12			6			5		1			
177.5	178.0	1493	1503	1	17		2	7			6		2			
178.0	178.5	1503	1513	1	16		3	9			1		3			
178.5	179.0	1513	1522	1	10		6	3			1					
179.0	179.5	1522	1531	1	17		4	6			4		3			
179.5	180.0	1531	1541	1	4			3			1					
180.0	180.5	1541	1550	1	4			4								
180.5	181.0	1550	1558	1	8		1	2			3		2			
181.0	181.5	1558	1567	1	7			5			1		1			
181.5	182.0	1567	1576	1	17		2	9			4		1			
182.0	182.5	1576	1585	1	88		21	24			17		24	1		
182.5	183.0	1585	1593	1	72		12	15			24		21			
183.0	183.5	1593	1602	1	30		4	12			8		3	1	1	
183.5	184.0	1602	1611	1	44		7	23			13		1			
184.0	184.5	1611	1620	1	50		11	18			16		5			
184.5	185.0	1620	1629	1	96		25	36			21		14			
185.0	185.5	1629	1638	1	17		5	7			4		1			
185.5	186.0	1638	1648	1	7		1	4			2					

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
186.0	186.5	1648	1658	1	10		4	3					2			
186.5	187.0	1658	1668	1	12		3	2			5		2			
187.0	187.5	1668	1678	1	10		3	6			1					
187.5	188.0	1678	1687	1	24		6	9			3		6			
188.0	188.5	1687	1697	1	24		7	10			6		1			
188.5	189.0	1697	1707	1	14		2	7			5					
189.0	189.5	1707	1716	1	27		6	13			4		4			
189.5	190.0	1716	1726	1	11		2	3			5		1			
190.0	190.5	1726	1736	1	17			5			5		7			
190.5	191.0	1736	1746	1	6		1	4					1			
191.0	191.5	1746	1755	1	12		1	9			2					
191.5	192.0	1755	1765	1	11		1	5			2		3			
192.0	192.5	1765	1775	1	8		2	1			4		1			
192.5	193.0	1775	1784	1	30		6	10			8		6			
193.0	193.5	1784	1794	1	28		1	9			11		6			
193.5	194.0	1794	1803	1	26		5	9			8		3			
194.0	194.5	1803	1813	1	21		4	10			6		1			
194.5	195.0	1813	1823	1	17		3	4			8		1			
195.0	195.5	1823	1832	1	13			6			4		3			
195.5	196.0	1832	1841	1	13		3	5			2		3			
196.0	196.5	1841	1850	1	9		3	2			3		1			
196.5	197.0	1850	1859	1	22		1	6			12		3			
197.0	197.5	1859	1868	1	20		2	9			6		3			
197.5	198.0	1868	1877	1	17		3	3			8		3			
198.0	198.5	1877	1886	1	13		3	3			4		3			
198.5	199.0	1886	1895	1	23		5	13			5					
199.0	199.5	1895	1905	1	48		10	15			15		7			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
199.5	200.0	1905	1914	1	17		2	11			1		3			
200.0	200.5	1914	1923	1	18		3	11			4					
200.5	201.0	1923	1932	1	66		9	28			20		9			
201.0	201.5	1932	1942	1	144		27	42			56		18			
201.5	202.0	1942	1951	1	91		16	31			26		18			
202.0	202.5	1951	1961	1	15		1	8			6					
202.5	203.0	1961	1971	1	10		1	5			2		2			
203.0	203.5	1971	1980	1	10		1	6			2		1			
203.5	204.0	1980	1989	1	6			5			1					
204.0	204.5	1989	1999	1	2			1			1					
204.5	205.0	1999	2008	1	2			2								
205.0	205.5	2008	2018	1	8		1	3			4					
205.5	206.0	2018	2027	1	6		1	2			3					
206.0	206.5	2027	2037	1	11		1	5			5					
206.5	207.0	2037	2046	1	8		1	3			2		2			
207.0	207.5	2046	2055	1	24		2	8			8		6			
207.5	208.0	2055	2065	1	27		9	6			3		6	1		
208.0	208.5	2065	2074	1	16	2	3	6			1		2	1		1
208.5	209.0	2074	2084	1	30	0	10	3			5		6			
209.0	209.5	2084	2093	1	24	1	3	10			2		5			1
209.5	210.0	2093	2102	1	23	1	0	5			5		7	2		
210.0	210.5	2102	2112	1	17	2	4	5			4		1			
210.5	211.0	2112	2120	1	75	3	22	12			8		24	5		1
211.0	211.5	2120	2129	1	64		11	8			10		23	5		
211.5	212.0	2129	2138	1	17		2	2			4		8	1		
212.0	212.5	2138	2147	1	13	1	5				3		3			
212.5	213.0	2147	2156	1	18		5	4			1		6			1

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
213.0	213.5	2156	2165	1	22	1	13	2			2		2	1		
213.5	214.0	2165	2174	1	15		5	1			2		6	1		
214.0	214.5	2174	2183	1	8		6						2			
214.5	215.0	2183	2192	1	10		5	2			2					
215.0	215.5	2192	2202	1	13		6	1					5			1
215.5	216.0	2202	2212	1	17		7	2					7			
216.0	216.5	2212	2222	1	21		5	1					11	3		
216.5	217.0	2222	2232	1	12		4	5					1	1		
217.0	217.5	2232	2242	1	28	1	8	7			3		8			
217.5	218.0	2242	2253	1	19	2	5	3			3		5	1		
218.0	218.5	2253	2263	1	41		8	6			5		20	1		
218.5	219.0	2263	2273	1	95	1	32	2			10		44	2		
219.0	219.5	2273	2283	1	58		12				3		38	3		
219.5	220.0	2283	2293	1	11		3	1			1		4			
220.0	220.5	2293	2303	1	5		1	2			1		1			
220.5	221.0	2303	2314	1	6		1	1			1		3			
221.0	221.5	2314	2324	1	6		1				1		2	2		
221.5	222.0	2324	2334	1	8		4				2		1			
222.0	222.5	2334	2345	1	12		1	2			4		5			
222.5	223.0	2345	2355	1	62		13	3			4		34	5		
223.0	223.5	2355	2365	1	19		4						12	1		
223.5	224.0	2365	2375	1	1		1									
224.0	224.5	2375	2385	1	6		3				2		1			
224.5	225.0	2385	2395	1	3		1	1					1			
225.0	225.5	2395	2405	1	11		5	5					1			
225.5	226.0	2405	2415	1	9		4						5			
226.0	226.5	2415	2425	1	13		3	2			3		3	1		

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
226.5	227.0	2425	2435	1	74		15	1			7		47	4		
227.0	227.5	2435	2445	1	40		12	3			7		17			
227.5	228.0	2445	2455	1	6			3			2		1			
228.0	228.5	2455	2465	1	12		1				2		7			
228.5	229.0	2465	2475	1	28		1	8			2		13	1		
229.0	229.5	2475	2485	1	21			6			4		6		4	
229.5	230.0	2485	2494	1	46		5	7			3		23	6		
230.0	230.5	2494	2504	1	42		1	11			5		22	1		
230.5	231.0	2504	2513	1	13		6	5					2			
231.0	231.5	2513	2522	1	19		1	8			1		8			
231.5	232.0	2522	2532	1	31		4	7			3		13			
232.0	232.5	2532	2541	1	14		4	2			5		2			
232.5	233.0	2541	2550	1	73		18				20		24	8		
233.0	233.5	2550	2560	1	129		50	7			25		28	11	1	
233.5	234.0	2560	2569	1	14		5				3		5			
234.0	234.5	2569	2578	1	6			1			4		1			
234.5	235.0	2578	2587	1	8		2				3					
235.0	235.5	2587	2597	1	7		3			1	1		1			
235.5	236.0	2597	2606	1	46		5				9		29	2		
236.0	236.5	2606	2615	1	49		6				8		31	2	1	
236.5	237.0	2615	2624	1	31		7				10		8	2		
237.0	237.5	2624	2634	1	35		8				6		20	1		
237.5	238.0	2634	2643	1	10		3	1			4		2			
238.0	238.5	2643	2653	1	13		7	1			1		4			
238.5	239.0	2653	2662	1	32		12				8		9			1
239.0	239.5	2662	2672	1	35		4	1			17		12			
239.5	240.0	2672	2682	1	13		4				3		5			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
240.0	240.5	2682	2690	1	8		4				2		2			
240.5	241.0	2690	2698	1	6		1				4		1			
241.0	241.5	2698	2707	1	7		2				2		3			
241.5	242.0	2707	2715	1	10		3	4			1		2			
242.0	242.5	2715	2724	1	26		9				7		7	1		
242.5	243.0	2724	2732	1	60		26	6			18		6	1		
243.0	243.5	2732	2741	1	128		45	4		2	43		19	8	4	
243.5	244.0	2741	2750	1	275		90	6		1	77		67	21	4	
244.0	244.5	2750	2758	1	33		8	1			7		10	3		
244.5	245.0	2758	2766	1	3		1	1			1					
245.0	245.5	2766	2772	1	7		1	2			4					
245.5	246.0	2772	2778	1	22		9			1	8		3		1	
246.0	246.5	2778	2783	1	6		3	1			1		1			
246.5	247.0	2783	2789	1	11		2	1			6		1			
247.0	247.5	2789	2795	1	3		1				1		1			
247.5	248.0	2795	2801	1	4		1	1			2					
248.0	248.5	2801	2807	1	7		2				1		4			
248.5	249.0	2807	2813	1	12		5				1		5	1		
249.0	249.5	2813	2819	1	6		2				1			3		
249.5	250.0	2819	2824	1	5		2				2		1			
250.0	250.5	2824	2830	1	22		7	1			7		6	1		
250.5	251.0	2830	2836	1	22		8				8		2	3		
251.0	251.5	2836	2842	1	14		1				5		6			
251.5	252.0	2842	2848	1	5						5					
252.0	252.5	2848	2853	1	7		1	1			1		2			
252.5	253.0	2853	2859	1	11		2				8		1			
253.0	253.5	2859	2865	1	6		4	1							1	

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
253.5	254.0	2865	2871	1	26		5	2			12		5		2	
254.0	254.5	2871	2876	1	99		28				15		42		9	
254.5	255.0	2876	2882	1	45		13	1			16		14			
255.0	255.5	2882	2888	1	25		8	3			8		4	2		
255.5	256.0	2888	2894	1	8		4				2		2			
256.0	256.5	2894	2900	1	52		25	6			13		6	1		
256.5	257.0	2900	2906	1	132		37	10			31		41	7	1	
257.0	257.5	2906	2913	1	33		12	4			1		10	6		
257.5	258.0	2913	2919	1	61		10	1		1	10		35	4		
258.0	258.5	2919	2925	1	6		1				4		1			
258.5	259.0	2925	2931	1	7		1	1		2	1		2			
259.0	259.5	2931	2938	1	4		4									
259.5	260.0	2938	2944	1	3		1				1			1		
260.0	260.5	2944	2954	1	6		2				3				1	
260.5	261.0	2954	2964	1	6		1	4					1			
261.0	261.5	2964	2974	1	11		4	3			3		1			
261.5	262.0	2974	2984	1	7		2	5								
262.0	262.5	2984	2994	1	3			1			1					
262.5	263.0	2994	3004	1	12		5				3		4			
263.0	263.5	3004	3014	1	18		2	1			3		12			
263.5	264.0	3014	3025	1	4						2		2			
264.0	264.5	3025	3034	1	4		1	2			1					
264.5	265.0	3034	3044	1	22		5	2			10		5			
265.0	265.5	3044	3055	1	40		7	5			8		19	1		
265.5	266.0	3055	3066	1	31		8	4			13		4	1		
266.0	266.5	3066	3077	1	30		10	6			10		3			
266.5	267.0	3077	3087	1	44		13	4		1	12		9	1		

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
267.0	267.5	3087	3098	1	112		27	3		1	43		32	2	1	
267.5	268.0	3098	3109	1	143		30	10			96		6			
268.0	268.5	3109	3119	1	25		4	3			18					
268.5	269.0	3119	3130	1	12		4				7		1			
269.0	269.5	3130	3141	1	9		1	3			4		1			
269.5	270.0	3141	3152	1	6			4			2					
270.0	270.5	3152	3163	1	3		2				1					
270.5	271.0	3163	3175	1	22		2	5			3		10	2		
271.0	271.5	3175	3186	1	11		1	3			5		2			
271.5	272.0	3186	3198	1	17		2				8		6			
272.0	272.5	3198	3209	1	46		4	5			11		26			
272.5	273.0	3209	3220	1	10			4			3		2			
273.0	273.5	3220	3232	1	10			5			4					
273.5	274.0	3232	3243	1	28		7	5			8		7			
274.0	274.5	3243	3255	1	17		2	5			5		5			
274.5	275.0	3255	3266	1	21		5	10			5					
275.0	275.5	3266	3278	1	72		8	21		2	19		21			
275.5	276.0	3278	3289	1	145		38	20			57		21	2		1
276.0	276.5	3289	3300	1	10		2	3			3		1			
276.5	277.0	3300	3312	1	5			2			2		1			
277.0	277.5	3312	3324	1	13		6	2			2		2	1		
277.5	278.0	3324	3335	1	10		3	3			1		3			
278.0	278.5	3335	3347	1	10		3	3			3		1			
278.5	279.0	3347	3358	1	19		2	5		1	5		5			
279.0	279.5	3358	3370	1	53		8	6			16		22	1		
279.5	280.0	3370	3381	1	21		3	4			1		13			
280.0	280.5	3381	3392	1	31		6	8			9		6		1	1

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
280.5	281.0	3392	3403	1	67		6	9			25		25	1		
281.0	281.5	3403	3414	1	55		10	8			16		20		1	
281.5	282.0	3414	3425	1	34		4	7			12		11			
282.0	282.5	3425	3436	1	11		2	1			4		4			
282.5	283.0	3436	3447	1	33		9	5			6		11			
283.0	283.5	3447	3458	1	9		2	2			4		1			
283.5	284.0	3458	3469	1	16		4	4			6		1			
284.0	284.5	3469	3481	1	61		22	13			16		10			
284.5	285.0	3481	3492	1	48		4	4			13		21		4	
285.0	285.5	3492	3503	1	19		2	4			6		5			
285.5	286.0	3503	3515	1	72		14	18			33		6			
286.0	286.5	3515	3527	1	153		34	42			49		20			
286.5	287.0	3527	3539	1	175		42	24			59		33	3	1	
287.0	287.5	3539	3551	1	181		47	36			57		29	2		
287.5	288.0	3551	3562	1	13		3				8		2			
288.0	288.5	3562	3574	1	8		2				2		3			
288.5	289.0	3574	3585	1	4						1		1	2		
289.0	289.5	3585	3597	1	15		2				4		9			
289.5	290.0	3597	3608	1	6		3				2		1			
290.0	290.5	3608	3620	1	22		4	1			10		7			
290.5	291.0	3620	3632	1	40		3	6			10		19	2		
291.0	291.5	3632	3643	1	11			2			5		3			
291.5	292.0	3643	3655	1	15			5			2		7	1		
292.0	292.5	3655	3667	1	13		1	4			4		3		1	
292.5	293.0	3667	3679	1	20		8	4			3		4			
293.0	293.5	3679	3691	1	16		5	5			3		3			
293.5	294.0	3691	3703	1	20		7				4		7	1		

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
294.0	294.5	3703	3715	1	40		9	5			15		11			
294.5	295.0	3715	3727	1	44		4	3			20		16			
295.0	295.5	3727	3738	1	51		10	2			16		16	5	2	
295.5	296.0	3738	3749	1	106		46	8			24		27	1		
296.0	296.5	3749	3761	1	33		7	1			6		15	3	1	
296.5	297.0	3761	3772	1	4		1				1		1			
297.0	297.5	3772	3784	1	8		2	1			4					
297.5	298.0	3784	3796	1	35		10	7		3	12		1	1		
298.0	298.5	3796	3807	1	7			1			3		3			
298.5	299.0	3807	3818	1	11			1			9		1			
299.0	299.5	3818	3830	1	6		1				4					
299.5	300.0	3830	3841	1	3			1					1	1		
300.0	300.5	3841	3853	1	12		1	3			5		2		1	
300.5	301.0	3853	3865	1	45		7	7			18		7	3		1
301.0	301.5	3865	3876	1	26		7	3			7		7			
301.5	302.0	3876	3888	1	41		8	6			10		13	3	1	
302.0	302.5	3888	3900	1	7			1			4		1			
302.5	303.0	3900	3912	1	14		5	3			5		1			
303.0	303.5	3912	3923	1	18		6	8			2		2			
303.5	304.0	3923	3935	1	13		5	4			2		2			
304.0	304.5	3935	3946	1	16		3	2			8		3			
304.5	305.0	3946	3958	1	20		7	3			8		1			
305.0	305.5	3958	3970	1	29		6	4			14		5			
305.5	306.0	3970	3982	1	199		39	17			77		52	7	2	
306.0	306.5	3982	3994	1	72		16	7			26		23			
306.5	307.0	3994	4007	1	14		2	4			5		3			
307.0	307.5	4007	4019	1	30		5	6			10		8			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
307.5	308.0	4019	4031	1	5						5					
308.0	308.5	4031	4044	1	5		1	1			3					
308.5	309.0	4044	4056	1	29		11	14			4					
309.0	309.5	4056	4069	1	7		1	1			5					
309.5	310.0	4069	4081	1	8		3	3			1		1			
310.0	310.5	4081	4092	1	60		24	26			10					
310.5	311.0	4092	4104	1	21		7	5			6		3			
311.0	311.5	4104	4115	1	29		10	5			8		4	1		
311.5	312.0	4115	4127	1	44		13	12			15					
312.0	312.5	4127	4138	1	70		15	14			22		15	1	1	
312.5	313.0	4138	4150	1	19		6	4			3		4		1	
313.0	313.5	4150	4161	1	11		3	3			4		1			
313.5	314.0	4161	4173	1	26		7	7			8		1			
314.0	314.5	4173	4184	1	12		1	1			5		4		1	
314.5	315.0	4184	4196	1	36		7	6			8		14		1	
315.0	315.5	4196	4207	1	25		9	4		1	6		4			
315.5	316.0	4207	4218	1	27		2	8		1	13		3			
316.0	316.5	4218	4229	1	24		8	3			9		2			
316.5	317.0	4229	4239	1	54		12	15			15		9	2	1	
317.0	317.5	4239	4250	1	159		29	29			69		26	2	1	
317.5	318.0	4250	4261	1	65		15	12			35		1			
318.0	318.5	4261	4272	1	5			3			1		1			
318.5	319.0	4272	4284	1	10		2	3			4					
319.0	319.5	4284	4295	1	9		1	6			2					
319.5	320.0	4295	4305	1	4		2	1			1					
320.0	320.5	4305	4317	1	30		2	9			11		6	1		
320.5	321.0	4317	4329	1	64		7	12		1	25		14	2	1	

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
321.0	321.5	4329	4341	1	61		11	8			33		8			
321.5	322.0	4341	4353	1	12		2	2			5				1	
322.0	322.5	4353	4365	1	9		1	3			2		3			
322.5	323.0	4365	4377	1	2			2								
323.0	323.5	4377	4389	1	65		16	30		1	14		4			
323.5	324.0	4389	4401	1	66		13	20			18		9		3	1
324.0	324.5	4401	4413	1	43		6	2		1	15		18	1		
324.5	325.0	4413	4425	1	16		3	6			3		4			
325.0	325.5	4425	4436	1	5		1	3			1					
325.5	326.0	4436	4447	1	21		4	4			10		3			
326.0	326.5	4447	4459	1	22		2	12			6		1	1		
326.5	327.0	4459	4470	1	19		5	4			6		4			
327.0	327.5	4470	4481	1	9		2	3			4					
327.5	328.0	4481	4492	1	20		5	8			5					
328.0	328.5	4492	4503	1	27		9	3			8		7			
328.5	329.0	4503	4514	1	19		5	5			5		3	1		
329.0	329.5	4514	4525	1	5			1			4					
329.5	330.0	4525	4536	1	9		5	3			1					
330.0	330.5	4536	4548	1	9			1			6		2			
330.5	331.0	4548	4559	1	3						2					1
331.0	331.5	4559	4570	1	23		4	6			5		7	1		
331.5	332.0	4570	4581	1	63		10	8			25		16			
332.0	332.5	4581	4592	1	55		11	3			24		12			
332.5	333.0	4592	4603	1	14		2	2			9		1			
333.0	333.5	4603	4614	1	42		6	5			19		12			
333.5	334.0	4614	4624	1	63		16	16			16		10	3		
334.0	334.5	4624	4635	1	61		26	21			8		3	1		

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
334.5	335.0	4635	4645	1	154		55	24			57		10	1		
335.0	335.5	4645	4656	1	26		6	4			12		4			
335.5	336.0	4656	4668	1	19		4	3			8		4			
336.0	336.5	4668	4679	1	20		3	4			6		7			
336.5	337.0	4679	4690	1	19		8	5			6					
337.0	337.5	4690	4701	1	11		4	2			5					
337.5	338.0	4701	4713	1	16		1	10			3		2			
338.0	338.5	4713	4724	1	16		2	4			5		4			
338.5	339.0	4724	4736	1	11		3	3			4		1			
339.0	339.5	4736	4747	1	19		2	4			9		4			
339.5	340.0	4747	4758	1	7		2	3			2					
340.0	340.5	4758	4769	1	16		3	8			4					
340.5	341.0	4769	4779	1	31		8	3			12		8			
341.0	341.5	4779	4790	1	7		1	2			2		2			
341.5	342.0	4790	4801	1	30		6	8			13		3			
342.0	342.5	4801	4812	1	201		29	33			82		43	10		
342.5	343.0	4812	4823	1	34		4	6			13		6	4		
343.0	343.5	4823	4834	1	12			6			4		2			
343.5	344.0	4834	4845	1	6			4			1					
344.0	344.5	4845	4855	1	9		3	3			3					
344.5	345.0	4855	4866	1	23		2	9			7		4	1		
345.0	345.5	4866	4877	1	17		5	7			5					
345.5	346.0	4877	4888	1	27		6	8			9		4			
346.0	346.5	4888	4898	1	203		92	29			45		27	6		
346.5	347.0	4898	4909	1	157		13	15			54		72	1		
347.0	347.5	4909	4920	1	73		17	20			22		11	1		
347.5	348.0	4920	4931	1	156		35	31			65		16	6		

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
348.0	348.5	4931	4942	1	18		2	7			6		3			
348.5	349.0	4942	4952	1	8		1	3			2		1			
349.0	349.5	4952	4963	1	13		3	4			6					
349.5	350.0	4963	4974	1	23		3	10			6		3	1		
350.0	350.5	4974	4984	1	18			9			7		2			
350.5	351.0	4984	4994	1	7		1	1			5					
351.0	351.5	4994	5004	1	26		3	7			11		4			
351.5	352.0	5004	5015	1	48		6	24			12		3	2		
352.0	352.5	5015	5025	1	43		5	9			17		10			
352.5	353.0	5025	5035	1	28		2	5			14		7			
353.0	353.5	5035	5045	1	27		1	6			11		9			
353.5	354.0	5045	5056	1	64		14	12			21		17			
354.0	354.5	5056	5066	1	120		41	38			29		12			
354.5	355.0	5066	5076	1	15		1	5			6		3			
355.0	355.5	5076	5087	1	13		1	2			4		6			
355.5	356.0	5087	5097	1	7		1	4			1		1			
356.0	356.5	5097	5108	1	12		2	1			5		4			
356.5	357.0	5108	5119	1	14		2	5			3		4			
357.0	357.5	5119	5129	1	19		1	6			7		5			
357.5	358.0	5129	5140	1	27		2	4			13		8			
358.0	358.5	5140	5151	1	79		6	13			30		30			
358.5	359.0	5151	5161	1	61		8	6			27		20			
359.0	359.5	5161	5172	1	20		4	6			5		5			
359.5	360.0	5172	5183	1	77		7	8			38		24			
360.0	360.5	5183	5193	1	42		8	10			15		8			
360.5	361.0	5193	5204	1	60		10	15			22		10	1		
361.0	361.5	5204	5215	1	42		8	12			15		7			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
361.5	362.0	5215	5226	1	256		50	54		1	110		40			
362.0	362.5	5226	5237	1	19		2	6			9		1			
362.5	363.0	5237	5247	1	15		3	7			5					
363.0	363.5	5247	5258	1	12		1	7			2		2			
363.5	364.0	5258	5269	1	3			1			2					
364.0	364.5	5269	5280	1	9		2	4			3					
364.5	365.0	5280	5291	1	7			2			5					
365.0	365.5	5291	5302	1	9		1	3			1		4			
365.5	366.0	5302	5314	1	14		2	2			6		3			
366.0	366.5	5314	5325	1	68		4	11			28		24			
366.5	367.0	5325	5337	1	22		5	5			7		5			
367.0	367.5	5337	5348	1	8		1	4			3					
367.5	368.0	5348	5360	1	15		3	3			6		3			
368.0	368.5	5360	5371	1	24		5	6			7		5			
368.5	369.0	5371	5383	1	10		1	3			4		2			
369.0	369.5	5383	5394	1	23		3	2			15		3			
369.5	370.0	5394	5406	1	40		4	6			21		9			
370.0	370.5	5406	5416	1	51		6	14			18		10	3		
370.5	371.0	5416	5426	1	37		5	8			16		8			
371.0	371.5	5426	5436	1	122		24	31			40		26	1		
371.5	372.0	5436	5446	1	274		40	64		1	101		64			2
372.0	372.5	5446	5456	1	5			3			1		1			
372.5	373.0	5456	5466	1	17			9			5		3			
373.0	373.5	5466	5476	1	8		1	4			3					
373.5	374.0	5476	5486	1	11		1	6			3		1			
374.0	374.5	5486	5496	1	17		2	9			2		4			
374.5	375.0	5496	5506	1	52		14	19			11		8			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
375.0	375.5	5506	5516	1	60		16	18			7		17		1	
375.5	376.0	5516	5527	1	31		6	11			10		4			
376.0	376.5	5527	5537	1	26		4	4			12		5			
376.5	377.0	5537	5548	1	56		8	16			21		11			
377.0	377.5	5548	5559	1	41		5	17			12		6	1		
377.5	378.0	5559	5570	1	14		4	4			4		2			
378.0	378.5	5570	5580	1	22		2	7			9		4			
378.5	379.0	5580	5591	1	29		5	9			9		5			
379.0	379.5	5591	5601	1	30		12	13			4		1			
379.5	380.0	5601	5612	1	89		16	18			22		30	1	1	
380.0	380.5	5612	5622	1	59		12	11			28		5			
380.5	381.0	5622	5633	1	31		3	6			12		10			
381.0	381.5	5633	5643	1	28		7	8			9		4			
381.5	382.0	5643	5654	1	32		7	7			7		10			
382.0	382.5	5654	5665	1	9		4	2			3					
382.5	383.0	5665	5675	1	9		2				4		3			
383.0	383.5	5675	5686	1	13		2	6			5					
383.5	384.0	5686	5697	1	16		1	6			6		3			
384.0	384.5	5697	5708	1	20		5	9			5		1			
384.5	385.0	5708	5719	1	26		3	8			8		7			
385.0	385.5	5719	5730	1	22		5	7			6		4			
385.5	386.0	5730	5741	1	126		20	34			36		33			
386.0	386.5	5741	5753	1	189		54	33		3	75		21			
386.5	387.0	5753	5764	1	22		3	11			5		3			
387.0	387.5	5764	5776	1	10		2	5					3			
387.5	388.0	5776	5787	1	24		1	6			11		4			
388.0	388.5	5787	5799	1	10		2	5			3					

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
388.5	389.0	5799	5811	1	15		3	4			4		4			
389.0	389.5	5811	5823	1	22		6	8			4		4			
389.5	390.0	5823	5835	1	12		2	3			2		5			
390.0	390.5	5835	5852	1	50		4	20		1	17		7			
390.5	391.0	5852	5868	1	39		3	6			20		9			
391.0	391.5	5868	5885	1	19		2	9			6		2			
391.5	392.0	5885	5902	1	8			5			3					
392.0	392.5	5902	5919	1	4		1	3								
392.5	393.0	5919	5936	1	14		1	4			5		2			
393.0	393.5	5936	5952	1	7		2	4					1			
393.5	394.0	5952	5969	1	74		43	19			6		6			
394.0	394.5	5969	5986	1	119		16	24			55		21	2		
394.5	395.0	5986	6002	1	134		13	36			64		19		1	
395.0	395.5	6002	6017	1	24		3	9			7		5			
395.5	396.0	6017	6033	1	91		9	31			32		16	1		
396.0	396.5	6033	6048	1	441		105	108			143		77	1	1	
396.5	397.0	6048	6063	1	85		12	35			25		13			
397.0	397.5	6063	6078	1	28		3	9			12		4			
397.5	398.0	6078	6093	1	5			3			2					
398.0	398.5	6093	6108	1	21		2	9			8		2			
398.5	399.0	6108	6123	1	9		2	5			2					
399.0	399.5	6123	6139	1	53		9	19			17		7			
399.5	400.0	6139	6154	1	38		10	15			10		3			
400.0	400.5	6154	6169	1	31		7	15			8		1			
400.5	401.0	6169	6184	1	43		7	17			17		2			
401.0	401.5	6184	6199	1	52		19	12			14		6		1	
401.5	402.0	6199	6214	1	46		5	15			20		6			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
402.0	402.5	6214	6229	1	24		5	11			6		2			
402.5	403.0	6229	6244	1	53		8	25			13		7			
403.0	403.5	6244	6259	1	71		11	25			27		7		1	
403.5	404.0	6259	6274	1	31		3	16			8		3			
404.0	404.5	6274	6288	1	14			10			3		1			
404.5	405.0	6288	6303	1	9			4			5					
405.0	405.5	6303	6319	1	18			10			6		2			
405.5	406.0	6319	6336	1	21		2	4			12		2	1		
406.0	406.5	6336	6352	1	27		7	7		2	8		2			1
406.5	407.0	6352	6368	1	148		26	68			39		14			
407.0	407.5	6368	6385	1	118		15	50			43		10			
407.5	408.0	6385	6401	1	73		14	28			25		5	1		
408.0	408.5	6401	6417	1	29		5	10			13		1			
408.5	409.0	6417	6433	1	20		2	15			3					
409.0	409.5	6433	6449	1	14		2	7			4		1			
409.5	410.0	6449	6465	1	26		6	6			11		3			
410.0	410.5	6465	6482	1	8		2	5			1					
410.5	411.0	6482	6500	1	1		1									
411.0	411.5	6500	6517	1	16		6	5			4				1	
411.5	412.0	6517	6535	1	32		5	7			11		5	1	3	
412.0	412.5	6535	6552	1	17		1	11			5					
412.5	413.0	6552	6569	1	34		4	14			12		3			
413.0	413.5	6569	6586	1	64		12	24			24		1	1		
413.5	414.0	6586	6604	1	103		21	44			31		6			
414.0	414.5	6604	6621	1	33		3	17			9		3			
414.5	415.0	6621	6638	1	8		4	2			2					
415.0	415.5	6638	6655	1	7			6			1					

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
415.5	416.0	6655	6672	1	34		8	18			8					
416.0	416.5	6672	6688	1	42		4	15			22		1			
416.5	417.0	6688	6705	1	28		3	11			14					
417.0	417.5	6705	6722	1	29		8	13			8					
417.5	418.0	6722	6739	1	19		9	6			2		2			
418.0	418.5	6739	6756	1	4			3			1					
418.5	419.0	6756	6772	1	29		7	7			13				2	
419.0	419.5	6772	6789	1	26		5	8			13					
419.5	420.0	6789	6805	1	41		7	22			9		3			
420.0	420.5	6805	6821	1	2			1					1			
420.5	421.0	6821	6836	1	5			2			1		2			
421.0	421.5	6836	6852	1	21		3	10			8					
421.5	422.0	6852	6868	1	12		4	4			4					
422.0	422.5	6868	6884	1	28		3	7			16		2			
422.5	423.0	6884	6899	1	45		5	13			21		4	1		
423.0	423.5	6899	6915	1	154		30	55			52		13	1		
423.5	424.0	6915	6931	1	49		7	11			29		2			
424.0	424.5	6931	6947	1	50		5	21			23		1			
424.5	425.0	6947	6963	1	44		4	13			22		4	1		
425.0	425.5	6963	6979	1	18		3	10			4		1			
425.5	426.0	6979	6995	1	41		9	16			13		2			
426.0	426.5	6995	7011	1	153		12	39			70		23	4		
426.5	427.0	7011	7028	1	17		3	5			7			2		
427.0	427.5	7028	7044	1	12		1	4			7					
427.5	428.0	7044	7060	1	7			3			4					
428.0	428.5	7060	7077	1	7		2	2			1		2			
428.5	429.0	7077	7093	1	27		5	9			11		2			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
429.0	429.5	7093	7109	1	9			5			4					
429.5	430.0	7109	7125	1	18		5	8			4		1			
430.0	430.5	7125	7139	1	17		3	3			5		5			
430.5	431.0	7139	7154	1	13		3	5			4		1			
431.0	431.5	7154	7169	1	17		5	5			6		1			
431.5	432.0	7169	7184	1	13		3	4			5		1			
432.0	432.5	7184	7199	1	27		1	12			11		3			
432.5	433.0	7199	7214	1	44		13	20			6		4			
433.0	433.5	7214	7229	1	11		3	5			2		1			
433.5	434.0	7229	7244	1	14		2	4			6		2			
434.0	434.5	7244	7260	1	49		17	7			17		8			
434.5	435.0	7260	7275	1	117		29	36			30		21			
435.0	435.5	7275	7290	1	50		3	23			19		5			
435.5	436.0	7290	7305	1	12		4	5					3			
436.0	436.5	7305	7321	1	12		1	3			4		4			
436.5	437.0	7321	7336	1	15		2	8			5					
437.0	437.5	7336	7351	1	7		1	3			1		2			
437.5	438.0	7351	7367	1	43		10	15			16		2			
438.0	438.5	7367	7383	1	35		5	16			12		2			
438.5	439.0	7383	7399	1	48		16	17		2	12		1			
439.0	439.5	7399	7414	1	1			1								
439.5	440.0	7414	7430	1	5		2	3								
440.0	440.5	7430	7447	1	13		3	6			3		1			
440.5	441.0	7447	7465	1	4		1	2			1					
441.0	441.5	7465	7483	1	27		5	11			11					
441.5	442.0	7483	7500	1	38		3	10			16		9			
442.0	442.5	7500	7518	1	77		7	13			39		17			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
442.5	443.0	7518	7534	1	12		2	2			6		2			
443.0	443.5	7534	7551	1	6			4			1				1	
443.5	444.0	7551	7568	1	18			14			4					
444.0	444.5	7568	7584	1	25		3	13			6		3			
444.5	445.0	7584	7601	1	73		17	28			22		4	2		
445.0	445.5	7601	7618	1	42		5	14			21		2			
445.5	446.0	7618	7636	1	53		16	26			10		1			
446.0	446.5	7636	7652	1	8		2	3			1		2			
446.5	447.0	7652	7670	1	8			2			5		1			
447.0	447.5	7670	7687	1	12		2	4			6					
447.5	448.0	7687	7704	1	24		2	6			14		1	1		
448.0	448.5	7704	7721	1	29		4	4			13		6	2		
448.5	449.0	7721	7738	1	48		7	23			11		3	2		
449.0	449.5	7738	7755	1	20		3	11			4		2			
449.5	450.0	7755	7772	1	16		6	5			5					
450.0	450.5	7772	7790	1	24		3	10			8		2			
450.5	451.0	7790	7807	1	20		4	6			9					
451.0	451.5	7807	7825	1	98		20	32		2	31		6	4	3	
451.5	452.0	7825	7842	1	32		6	12			6		3	3		
452.0	452.5	7842	7860	1	29		1	14			10		3	1		
452.5	453.0	7860	7877	1	25		5	13			5		2			
453.0	453.5	7877	7894	1	69		18	25			21		2	2		
453.5	454.0	7894	7912	1	32		4	15			12		1			
454.0	454.5	7912	7929	1	7		1	5			1					
454.5	455.0	7929	7946	1	9		1	3			4		1			
455.0	455.5	7946	7964	1	6		1	1			3					
455.5	456.0	7964	7981	1	2						1		1			

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
456.0	456.5	7981	7999	1	3						2		1			
456.5	457.0	7999	8017	1	3		1	2								
457.0	457.5	8017	8035	1	9		2	4			3					
457.5	458.0	8035	8053	1	32		2	10			11		6	3		
458.0	458.5	8053	8070	1	38		3	9			20		6			
458.5	459.0	8070	8089	1	27		6	9			10		1		1	
459.0	459.5	8089	8106	1	34		10	10			12		1	1		
459.5	460.0	8106	8123	1	33		9	11			10		3			
460.0	460.5	8123	8140	1	86		20	25			36		5			
460.5	461.0	8140	8157	1	247		46	56			90		39	10	2	
461.0	461.5	8157	8174	1	9		1	5			1		1	1		
461.5	462.0	8174	8191	1	21			9			11		1			
462.0	462.5	8191	8208	1	21		3	9			9					
462.5	463.0	8208	8225	1	17		3	7			5		2			
463.0	463.5	8225	8242	1	17		2	11			3		1			
463.5	464.0	8242	8260	1	9		4	2					3			
464.0	464.5	8260	8277	1	6		3	2					1			
464.5	465.0	8277	8294	1	22		5	9			8					
465.0	465.5	8294	8311	1	54		15	25			11		3			
465.5	466.0	8311	8329	1	18		3	10			5					
466.0	466.5	8329	8346	1	52		13	15			23		1			
466.5	467.0	8346	8363	1	21		8	8			3		1			
467.0	467.5	8363	8380	1	18		4	4			8		2			
467.5	468.0	8380	8398	1	26		4	13			9					
468.0	468.5	8398	8415	1	55		9	17			22		6			
468.5	469.0	8415	8432	1	18		2	6			9		1			
469.0	469.5	8432	8450	1	12		3	4			5					

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
469.5	470.0	8450	8467	1	19		3	11			2		3			
470.0	470.5	8467	8484	1	25		6	10			9					
470.5	471.0	8484	8502	1	34		15	10			6		3			
471.0	471.5	8502	8520	1	58		17	28			10		3			
471.5	472.0	8520	8537	1	9		2	5			2					
472.0	472.5	8537	8555	1	4			1			3					
472.5	473.0	8555	8573	1	10		1	5			3		1			
473.0	473.5	8573	8590	1	25		6	8			8		3			
473.5	474.0	8590	8608	1	38		12	7			16		2			
474.0	474.5	8608	8626	1	29		10	11			3		1	1	1	
474.5	475.0	8626	8643	1	45		14	18			12				1	
475.0	475.5	8643	8661	1	18		4	9			5					
475.5	476.0	8661	8679	1	40		7	15			17		1			
476.0	476.5	8679	8697	1	18			6			9		3			
476.5	477.0	8697	8715	1	44		9	23			8		4			
477.0	477.5	8715	8733	1	9		1	5			2		1			
477.5	478.0	8733	8751	1	9			4			3		2			
478.0	478.5	8751	8769	1	22		3	8			9		1	1		
478.5	479.0	8769	8787	1	161		20	60			51		23	2		
479.0	479.5	8787	8805	1	328		40	102			134		33	10	1	
479.5	480.0	8805	8823	1	35		8	14			13					
480.0	480.5	8823	8840	1	12			6			5		1			
480.5	481.0	8840	8858	1	8		2	3			3					
481.0	481.5	8858	8876	1	14			9			5					
481.5	482.0	8876	8894	1	30		1	15			9		3	1	1	
482.0	482.5	8894	8912	1	26		1	14			8		1			
482.5	483.0	8912	8929	1	22			12			10					

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
483.0	483.5	8929	8947	1	109		21	54			25		7		2	
483.5	484.0	8947	8965	1	34		6	16			11		1			
484.0	484.5	8965	8983	1	8			5			3					
484.5	485.0	8983	9001	1	74		6	30			33		4	1		
485.0	485.5	9001	9026	1	45		4	27			9		3	1	1	
485.5	486.0	9026	9051	1	34		6	19			6		2	1		
486.0	486.5	9051	9076	1	29		7	14			5		3			
486.5	487.0	9076	9103	1	41		3	17			19		1	1		
487.0	487.5	9103	9129	1	22			14			6			2		
487.5	488.0	9129	9155	1	35		6	16			9		4			
488.0	488.5	9155	9181	1	39		6	12			19		1	1		
488.5	489.0	9181	9207	1	188		17	65			83		18	5		
489.0	489.5	9207	9233	1	73		11	31			24		1	3		
489.5	490.0	9233	9259	1	11		1	8			2					
490.0	490.5	9259	9295	1	54		8	27			18		1			
490.5	491.0	9295	9330	1	53		6	30			9		6	1		
491.0	491.5	9330	9366	1	62		7	19			23		7	6		
491.5	492.0	9366	9403	1	46		6	22			17			1		
492.0	492.5	9403	9438	1	31		8	14			9					
492.5	493.0	9438	9474	1	11			8		1	1		1			
493.0	493.5	9474	9509	1	10			8			1		1			
493.5	494.0	9509	9544	1	10		2	3			4		1			
494.0	494.5	9544	9579	1	21		2	9			8		1			
494.5	495.0	9579	9615	1	14		1	6			6		1			
495.0	495.5	9615	9648	1	42		8	18			10		4	2		
495.5	496.0	9648	9681	1	84		25	31			18		9			
496.0	496.5	9681	9714	1	53		8	23			11		8	3		

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
496.5	497.0	9714	9748	1	42		8	20			10		2	2		
497.0	497.5	9748	9781	1	49		10	28			2		7		1	
497.5	498.0	9781	9813	1	32		5	12			10		3			
498.0	498.5	9813	9845	1	70		14	27			19		6	3	1	
498.5	499.0	9845	9877	1	49		15	18		1	13		2			
499.0	499.5	9877	9909	1	23		5	11			3		2	1		
499.5	500.0	9909	9940	1	43		12	12			12		4	1		
500.0	500.5	9940	9974	1	33		6	12			12		2			
500.5	501.0	9974	10009	1	41		8	14			16		1	2		
501.0	501.5	10009	10044	1	40		7	18			12		2			
501.5	502.0	10044	10080	1	15		3	7			3		2			
502.0	502.5	10080	10114	1	42		10	16			16					
502.5	503.0	10114	10149	1	85		16	34			26		7	1	1	
503.0	503.5	10149	10184	1	36		3	24			8		1			
503.5	504.0	10184	10217	1	12		3	6			1		2			
504.0	504.5	10217	10251	1	13		4	8			1					
504.5	505.0	10251	10285	1	15		4	6			3		2			
505.0	505.5	10285	10319	1	26		5	6			14		1			
505.5	506.0	10319	10352	1	12		2	6			3		1			
506.0	506.5	10352	10386	1	7		1	5								
506.5	507.0	10386	10419	1	7		3	2			2					
507.0	507.5	10419	10454	1	12		3	6			3					
507.5	508.0	10454	10487	1	3		1	1			1					
508.0	508.5	10487	10521	1	3		1	2								
508.5	509.0	10521	10553	1	4			3			1					
509.0	509.5	10553	10587	1	7		3	3			1					
509.5	510.0	10587	10620	1	12		2	9			1					

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
510.0	510.5	10620	10653	1	5		2	1					2			
510.5	511.0	10653	10685	1	3		2						1			
511.0	511.5	10685	10717	1	7			3			3					
511.5	512.0	10717	10749	1	4		1	2			1					
512.0	512.5	10749	10782	1	2			1			1					
512.5	513.0	10782	10814	1	5			2			1		1			
513.0	513.5	10814	10847	1	10		1	6			2		1			
513.5	514.0	10847	10879	1	28		7	6			8		6			
514.0	514.5	10879	10912	1	28			11			16					
514.5	515.0	10912	10944	1	140		17	64			38		7			
515.0	515.5	10944	10978	1	4		1	1					1			
515.5	516.0	10978	11012	1	4			3					1			
516.0	516.5	11012	11047	1	3			2			1					
516.5	517.0	11047	11082	1	2			1					1			
517.0	517.5	11082	11116	1	36		4	24			5		3			
517.5	518.0	11116	11151	1	1								1			
518.0	518.5	11151	11185	1	1						1					
518.5	519.0	11185	11220	1	3		2	1								
519.0	519.5	11220	11254	1	5			4			1					
519.5	520.0	11254	11288	1	1			1								
520.0	520.5	11288	11322	1	2			1			1					
520.5	521.0	11322	11356	1	2			2								
521.0	521.5	11356	11390	1	9		1	3			5					
521.5	522.0	11390	11424	1	3		2				1					
522.0	522.5	11424	11458	1	6		1	2			3					
522.5	523.0	11458	11492	1	4		1	3								
523.0	523.5	11492	11525	1	5			4			1					

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype										
						A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
523.5	524.0	11525	11560	1	3			1			2					
524.0	524.5	11560	11594	1	2			2								
524.5	525.0	11594	11628	1	1						1					
525.0	525.5	11628	11661	1	0											
525.5	526.0	11661	11694	1	1		1									
526.0	526.5	11694	11728	1	2		1	1								
526.5	527.0	11728	11762	1	1						1					
527.0	527.5	11762	11796	1	1						1					
527.5	528.0	11796	11830	1	0											
528.0	528.5	11830	11864	1	0											
528.5	529.0	11864	11898	1	0											
529.0	529.5	11898	11932	1	0											
529.5	530.0	11932	11966	1	0											
530.0	530.5	11966	11992	1	1			1								
530.5	531.0	11992	12018	1	0											
531.0	531.5	12018	12044	1	1			1								
531.5	532.0	12044	12069	1	2			2								
532.0	532.5	12069	12096	1	0											
532.5	533.0	12096	12121	1	4			4								
533.0	533.5	12121	12146	1	1											
533.5	534.0	12146	12171	1	0											
534.0	534.5	12171	12197	1	0											
534.5	535.0	12197	12221	1	0											
535.0	535.5	12221	12247	1	0											
535.5	536.0	12247	12273	1	0											
536.0	536.5	12273	12298	1	0											
536.5	537.0	12298	12324	1	0											

Top (cm)	Bot (cm)	TopAge (yr BP)	BotAge (yr BP)	CharVol (cm^3)	Char Count (#)	Charcoal morphotype A2	A3	B1	B2	B3	B4	B5	B6	C1	C5	C7
537.0	537.5	12324	12349	1	0											
537.5	538.0	12349	12375	1	0											
538.0	538.5	12375	12399	1	0											
538.5	539.0	12399	12424	1	0											
539.0	539.5	12424	12449	1	0											

Table II – Water content, LOI and magnetic susceptibility for Spindly Pine Lake sediment core.

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
0.00	0.50	99.54	82.05	3.49	14.46	-7.44
0.50	1.00	99.53	78.05	3.32	18.63	-1.50
1.00	1.50	99.32	71.01	7.88	21.10	-4.21
1.50	2.00	99.12	76.92	0.00	23.08	2.82
2.00	2.50	99.00	73.79	5.28	20.93	-5.89
2.50	3.00	98.86	77.22	0.00	22.78	-5.44
3.00	3.50	99.07	70.00	5.10	24.90	-3.21
3.50	4.00	98.66	81.25	0.94	17.81	1.95
4.00	4.50	97.99	79.88	0.00	20.12	-6.37
4.50	5.00	98.29	77.30	0.00	22.70	-3.24
5.00	5.50	98.31	79.11	0.00	20.89	-3.69

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
5.50	6.00	98.16	71.91	0.76	27.33	-7.24
6.00	6.50	98.11	75.76	0.00	24.24	-1.96
6.50	7.00	98.03	76.51	0.82	22.67	2.84
7.00	7.50	98.05	80.67	0.00	19.33	2.75
7.50	8.00	97.71	66.12	3.89	29.99	2.59
8.00	8.50	97.42	67.27	0.62	32.11	1.65
8.50	9.00	97.86	69.65	0.00	30.35	6.04
9.00	9.50	97.75	65.26	7.16	27.58	-2.10
9.50	10.00	97.05	70.39	0.00	29.61	-2.50
10.00	10.50	96.31	67.15	3.14	29.72	11.63
10.50	11.00	95.73	65.93	2.71	31.36	6.79
11.00	11.50	96.04	68.49	2.24	29.27	11.12
11.50	12.00	96.72	68.14	3.21	28.65	4.71
12.00	12.50	96.39	62.34	3.89	33.78	2.63
12.50	13.00	95.78	61.79	2.97	35.24	-1.81
13.00	13.50	95.62	60.75	4.18	35.08	12.71
13.50	14.00	95.65	63.95	0.00	36.05	8.01
14.00	14.50	96.22	63.42	0.72	35.86	1.61
14.50	15.00	96.13	60.17	5.76	34.07	4.41
15.00	15.50	94.57	59.24	0.00	40.76	14.87
15.50	16.00	93.99	56.91	2.40	40.69	6.13
16.00	16.50	95.88	63.67	0.44	35.90	4.76
16.50	17.00	96.18	62.56	2.73	34.70	-5.31
17.00	17.50	95.97	66.17	0.81	33.02	10.51
17.50	18.00	95.70	63.91	1.02	35.07	5.26
18.00	18.50	96.11	64.69	2.35	32.96	-1.91

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
18.50	19.00	96.66	62.72	3.22	34.06	-4.51
19.00	19.50	95.87	61.76	3.84	34.41	-4.32
19.50	20.00	95.54	62.33	1.86	35.81	-1.94
20.00	20.50	96.61	64.00	3.17	32.83	5.90
20.50	21.00	96.29	63.11	3.96	32.93	10.57
21.00	21.50	97.36	65.37	5.29	29.34	4.83
21.50	22.00	97.64	69.86	1.24	28.89	10.80
22.00	22.50	96.92	66.90	1.45	31.64	6.37
22.50	23.00	96.79	64.47	2.68	32.84	2.34
23.00	23.50	97.48	65.16	2.37	32.47	1.18
23.50	24.00	95.49	64.45	2.92	32.62	1.08
24.00	24.50	96.94	66.80	0.55	32.65	7.90
24.50	25.00	97.19	68.99	2.64	28.37	7.52
25.00	25.50	96.12	66.58	0.37	33.06	8.29
25.50	26.00	96.22	64.29	1.44	34.28	30.54
26.00	26.50	96.13	61.96	1.48	36.57	8.97
26.50	27.00	96.63	62.71	1.50	35.79	2.15
27.00	27.50	96.54	66.91	3.91	29.18	-3.87
27.50	28.00	97.01	66.67	1.43	31.90	13.01
28.00	28.50	95.78	63.54	2.25	34.21	12.44
28.50	29.00	96.09	59.21	1.79	39.00	9.69
29.00	29.50	95.16	60.91	6.72	32.38	10.55
29.50	30.00	94.99	60.89	1.59	37.52	15.46
30.00	30.50	95.08	60.40	4.92	34.68	11.87
30.50	31.00	94.68	58.33	5.38	36.28	17.50
31.00	31.50	94.27	58.33	2.44	39.22	22.13

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
31.50	32.00	94.17	57.36	2.31	40.33	13.11
32.00	32.50	93.55	56.91	2.94	40.15	14.82
32.50	33.00	94.11	60.66	0.53	38.81	14.37
33.00	33.50	94.32	58.77	3.30	37.93	16.01
33.50	34.00	94.94	58.66	2.22	39.13	22.12
34.00	34.50	94.20	57.12	3.23	39.66	25.83
34.50	35.00	94.58	58.48	2.71	38.80	17.49
35.00	35.50	94.38	57.50	0.25	42.25	13.09
35.50	36.00	94.64	52.60	4.81	42.59	14.71
36.00	36.50	94.86	55.89	4.71	39.40	15.15
36.50	37.00	94.82	57.23	2.25	40.52	15.98
37.00	37.50	92.83	57.45	2.21	40.34	7.75
37.50	38.00	94.19	56.03	3.99	39.99	7.26
38.00	38.50	94.54	57.52	0.95	41.53	9.57
38.50	39.00	94.87	56.20	5.96	37.84	28.04
39.00	39.50	94.55	59.54	2.34	38.12	24.36
39.50	40.00	94.76	57.30	2.96	39.74	12.87
40.00	40.50	95.40	57.23	0.79	41.99	27.93
40.50	41.00	94.02	60.28	0.23	39.49	15.18
41.00	41.50	93.79	57.93	2.90	39.17	11.40
41.50	42.00	94.39	57.59	4.23	38.18	16.31
42.00	42.50	95.63	58.15	3.21	38.64	12.34
42.50	43.00	94.08	56.92	3.60	39.48	14.91
43.00	43.50	94.66	57.05	1.50	41.45	14.51
43.50	44.00	94.96	54.77	3.63	41.60	11.52
44.00	44.50	94.25	54.94	1.61	43.45	11.43

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
44.50	45.00	94.72	56.78	1.42	41.80	15.10
45.00	45.50	93.63	54.31	2.07	43.61	17.91
45.50	46.00	93.66	52.58	1.70	45.72	10.73
46.00	46.50	93.13	51.53	3.08	45.39	20.01
46.50	47.00	93.27	53.00	1.75	45.25	18.88
47.00	47.50	93.38	52.62	2.89	44.48	20.45
47.50	48.00	92.68	51.90	3.07	45.03	48.82
48.00	48.50	83.53	54.22	4.08	41.70	93.26
48.50	49.00	84.25	54.53	3.27	42.20	15.19
49.00	49.50	82.91	54.88	3.89	41.23	6.70
49.50	50.00	83.68	53.24	4.03	42.73	7.63
50.00	50.50	83.15	52.96	4.87	42.17	8.28
50.50	51.00	82.95	54.12	4.64	41.24	9.28
51.00	51.50	82.91	55.39	3.96	40.65	9.78
51.50	52.00	83.63	56.94	4.83	38.23	8.83
52.00	52.50	84.99	57.44	7.59	34.97	7.65
52.50	53.00	n/a	n/a	n/a	n/a	4.91
53.00	53.50	84.01	58.72	2.04	39.25	11.77
53.50	54.00	85.07	59.11	3.97	36.91	7.48
54.00	54.50	84.67	59.60	1.44	38.96	9.24
54.50	55.00	85.31	59.69	2.12	38.19	7.88
55.00	55.50	84.76	60.31	1.71	37.98	7.31
55.50	56.00	84.91	58.99	2.89	38.12	6.50
56.00	56.50	84.86	58.21	4.11	37.68	6.27
56.50	57.00	84.99	57.18	5.13	37.69	8.24
57.00	57.50	83.90	52.93	1.12	45.95	8.85

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
57.50	58.00	84.83	51.64	2.18	46.18	3.21
58.00	58.50	84.29	52.70	2.31	44.99	4.24
58.50	59.00	84.98	52.08	2.35	45.57	4.00
59.00	59.50	84.69	51.77	2.45	45.78	5.20
59.50	60.00	83.84	53.73	2.90	43.37	7.27
60.00	60.50	85.40	55.70	2.28	42.03	3.84
60.50	61.00	84.97	55.30	2.08	42.62	5.20
61.00	61.50	84.73	55.16	1.69	43.16	5.68
61.50	62.00	83.69	52.71	1.67	45.62	10.28
62.00	62.50	83.54	52.61	2.81	44.58	6.28
62.50	63.00	80.72	57.45	3.60	38.95	2.98
63.00	63.50	82.29	51.92	4.48	43.59	4.19
63.50	64.00	84.24	52.14	5.34	42.51	6.03
64.00	64.50	82.03	51.94	2.63	45.43	8.06
64.50	65.00	82.75	52.63	1.92	45.45	9.90
65.00	65.50	81.32	51.68	7.43	40.89	6.78
65.50	66.00	82.82	53.07	4.91	42.02	7.02
66.00	66.50	84.01	56.67	3.32	40.01	6.21
66.50	67.00	n/a	n/a	n/a	n/a	7.00
67.00	67.50	86.09	55.51	6.50	37.99	6.80
67.50	68.00	85.34	57.61	3.50	38.89	7.33
68.00	68.50	n/a	n/a	n/a	n/a	1.66
68.50	69.00	n/a	n/a	n/a	n/a	3.32
69.00	69.50	n/a	n/a	n/a	n/a	2.73
69.50	70.00	84.84	56.28	3.01	40.71	3.82
70.00	70.50	84.29	55.81	4.74	39.44	3.95

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
70.50	71.00	84.64	55.53	3.11	41.35	5.13
71.00	71.50	84.22	54.30	2.26	43.44	5.10
71.50	72.00	83.90	57.56	1.58	40.86	4.81
72.00	72.50	84.42	53.20	1.80	45.00	4.57
72.50	73.00	84.49	53.98	2.14	43.88	5.76
73.00	73.50	84.13	53.41	3.34	43.26	3.91
73.50	74.00	83.72	52.40	3.04	44.56	5.89
74.00	74.50	84.48	52.32	2.10	45.58	7.35
74.50	75.00	83.35	52.79	3.29	43.93	6.14
75.00	75.50	84.21	51.89	3.83	44.28	7.26
75.50	76.00	84.17	53.86	1.36	44.78	8.60
76.00	76.50	83.59	56.03	1.93	42.04	7.32
76.50	77.00	83.03	54.46	1.35	44.20	5.47
77.00	77.50	n/a	n/a	n/a	n/a	6.61
77.50	78.00	84.70	55.00	2.67	42.33	-2.24
78.00	78.50	84.37	54.12	3.85	42.03	-2.84
78.50	79.00	84.02	55.54	2.46	42.00	-2.67
79.00	79.50	84.07	55.58	2.67	41.75	-5.05
79.50	80.00	80.04	51.33	3.61	45.06	-4.06
80.00	80.50	84.44	55.60	1.02	43.37	-3.68
80.50	81.00	82.86	57.49	0.76	41.75	-2.81
81.00	81.50	83.82	53.33	3.90	42.78	-8.80
81.50	82.00	83.77	53.79	2.58	43.64	-3.31
82.00	82.50	84.03	52.53	4.17	43.30	-2.04
82.50	83.00	82.95	54.05	3.12	42.83	-4.11
83.00	83.50	84.63	53.04	4.38	42.58	-1.87

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
83.50	84.00	84.15	54.97	0.50	44.53	-2.32
84.00	84.50	84.25	54.96	0.61	44.43	-1.95
84.50	85.00	83.04	51.68	2.59	45.73	-1.05
85.00	85.50	83.39	54.33	3.93	41.74	-2.65
85.50	86.00	83.18	53.91	1.84	44.25	-1.51
86.00	86.50	83.43	55.16	2.73	42.11	-1.92
86.50	87.00	83.73	56.81	2.23	40.96	-3.78
87.00	87.50	83.30	55.73	3.12	41.15	-3.28
87.50	88.00	84.25	54.88	4.42	40.70	-3.77
88.00	88.50	83.73	52.89	3.44	43.67	-3.45
88.50	89.00	83.35	50.47	2.90	46.63	-5.63
89.00	89.50	82.25	45.50	3.08	51.42	-4.39
89.50	90.00	82.40	47.22	2.42	50.36	78.61
90.00	90.50	83.08	50.94	2.66	46.39	1.89
90.50	91.00	83.95	53.69	4.81	41.50	-6.25
91.00	91.50	83.71	51.06	2.18	46.76	-5.47
91.50	92.00	83.74	54.22	4.92	40.87	-4.75
92.00	92.50	85.41	55.83	3.44	40.73	-8.15
92.50	93.00	83.99	54.25	3.07	42.67	-4.14
93.00	93.50	83.85	53.56	4.05	42.39	-7.13
93.50	94.00	83.71	56.79	6.63	36.57	-4.59
94.00	94.50	85.22	58.41	2.35	39.24	-4.83
94.50	95.00	83.24	56.40	4.90	38.70	-6.93
95.00	95.50	84.80	56.89	3.00	40.10	-3.36
95.50	96.00	84.16	57.18	3.06	39.76	-4.05
96.00	96.50	84.65	55.97	3.27	40.76	-3.00

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
96.50	97.00	85.95	65.72	3.12	31.15	-5.07
97.00	97.50	82.96	58.75	0.97	40.28	-3.85
97.50	98.00	84.11	54.35	3.67	41.99	-3.62
98.00	98.50	82.56	55.42	6.42	38.16	-4.97
98.50	99.00	82.32	51.18	7.10	41.72	-3.57
99.00	99.50	83.07	54.11	2.29	43.60	-3.95
99.50	100.00	81.83	52.84	0.80	46.36	-4.65
100.00	100.50	83.12	53.89	2.98	43.13	3.32
100.50	101.00	80.55	53.38	2.93	43.69	-1.48
101.00	101.50	82.95	55.49	2.64	41.87	-2.02
101.50	102.00	81.76	55.48	2.94	41.58	-3.03
102.00	102.50	n/a	n/a	n/a	n/a	-3.20
102.50	103.00	82.64	55.81	1.68	42.51	-2.85
103.00	103.50	n/a	n/a	n/a	n/a	-1.89
103.50	104.00	86.22	55.37	2.92	41.71	-5.45
104.00	104.50	86.03	55.73	2.04	42.23	-5.93
104.50	105.00	85.75	55.93	2.08	42.00	-5.49
105.00	105.50	85.79	55.11	2.07	42.82	-6.68
105.50	106.00	85.70	53.63	2.09	44.28	2.97
106.00	106.50	84.74	52.61	2.26	45.12	-3.56
106.50	107.00	84.88	53.80	2.44	43.76	-2.91
107.00	107.50	84.19	54.58	3.08	42.34	-2.89
107.50	108.00	85.98	54.95	2.13	42.92	-6.11
108.00	108.50	85.98	53.50	4.39	42.11	-7.20
108.50	109.00	86.07	52.79	4.43	42.78	-7.30
109.00	109.50	84.98	51.73	2.74	45.53	-8.52

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
109.50	110.00	86.00	52.68	1.84	45.48	-5.81
110.00	110.50	85.75	52.86	5.75	41.39	-7.65
110.50	111.00	86.04	55.39	1.69	42.92	-9.34
111.00	111.50	86.73	56.28	2.02	41.70	-4.84
111.50	112.00	86.17	55.50	2.82	41.68	-6.07
112.00	112.50	85.44	47.97	1.76	50.28	-8.91
112.50	113.00	86.46	52.76	1.88	45.36	-7.47
113.00	113.50	86.88	54.43	2.33	43.25	-8.58
113.50	114.00	85.14	53.89	2.20	43.90	-8.20
114.00	114.50	86.07	55.06	3.44	41.51	-8.06
114.50	115.00	85.85	55.55	1.57	42.88	-8.38
115.00	115.50	86.48	56.88	1.41	41.71	-8.86
115.50	116.00	85.95	51.70	7.91	40.39	-9.16
116.00	116.50	86.12	51.00	10.44	38.56	-7.29
116.50	117.00	85.63	56.55	1.27	42.18	-6.79
117.00	117.50	86.65	56.90	2.58	40.52	-6.67
117.50	118.00	87.50	58.72	0.25	41.03	-7.19
118.00	118.50	87.04	54.94	2.76	42.30	-9.49
118.50	119.00	87.34	58.51	1.73	39.76	-8.71
119.00	119.50	87.25	56.53	2.44	41.03	-5.76
119.50	120.00	87.68	58.22	1.92	39.86	-7.62
120.00	120.50	87.72	56.99	1.55	41.46	-7.59
120.50	121.00	87.24	56.96	1.58	41.47	-8.83
121.00	121.50	87.66	56.74	2.94	40.32	-7.63
121.50	122.00	87.24	56.57	1.32	42.10	-7.90
122.00	122.50	87.38	55.76	2.44	41.80	-5.74

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
122.50	123.00	87.19	53.66	1.93	44.41	-7.33
123.00	123.50	87.54	55.42	1.19	43.39	-6.04
123.50	124.00	87.55	54.62	1.14	44.24	-6.59
124.00	124.50	87.65	57.14	0.72	42.14	-9.64
124.50	125.00	88.20	56.83	1.89	41.28	-8.07
125.00	125.50	87.62	53.10	3.01	43.89	-7.67
125.50	126.00	87.48	56.47	2.51	41.02	-9.53
126.00	126.50	86.76	50.78	0.89	48.33	-6.54
126.50	127.00	87.18	53.48	2.13	44.39	-7.49
127.00	127.50	n/a	n/a	n/a	n/a	-6.66
127.50	128.00	88.26	54.80	2.18	43.02	-1.29
128.00	128.50	87.42	56.83	1.83	41.34	-2.81
128.50	129.00	88.45	53.31	1.65	45.04	-4.45
129.00	129.50	89.00	54.72	2.48	42.80	-3.44
129.50	130.00	88.58	55.42	2.09	42.48	-5.82
130.00	130.50	89.18	54.46	1.96	43.58	-6.66
130.50	131.00	87.22	49.71	1.75	48.54	-3.67
131.00	131.50	85.84	48.94	0.90	50.17	-4.06
131.50	132.00	88.86	52.11	2.10	45.79	-3.83
132.00	132.50	87.68	50.97	2.77	46.26	-4.88
132.50	133.00	86.99	48.80	3.27	47.93	-6.05
133.00	133.50	87.69	53.06	1.00	45.94	-4.91
133.50	134.00	87.25	55.15	2.31	42.54	-6.98
134.00	134.50	87.19	54.87	1.67	43.46	-2.47
134.50	135.00	86.98	52.69	2.57	44.74	-1.16
135.00	135.50	86.53	50.88	1.67	47.45	-2.10

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
135.50	136.00	86.55	52.83	2.67	44.49	-3.09
136.00	136.50	86.73	51.38	1.58	47.04	2.22
136.50	137.00	85.95	49.42	1.95	48.63	-2.42
137.00	137.50	85.36	49.84	1.62	48.54	1.25
137.50	138.00	86.40	51.56	1.99	46.46	2.03
138.00	138.50	86.31	49.91	1.89	48.20	-3.72
138.50	139.00	86.20	50.35	2.67	46.98	-4.94
139.00	139.50	85.56	48.93	2.30	48.77	-1.48
139.50	140.00	86.27	48.90	1.78	49.33	-5.46
140.00	140.50	86.13	48.66	2.01	49.33	-2.33
140.50	141.00	85.65	47.28	2.55	50.17	-1.31
141.00	141.50	85.54	45.74	2.06	52.20	-1.14
141.50	142.00	85.49	47.03	2.48	50.48	3.09
142.00	142.50	85.14	46.12	2.87	51.01	-2.29
142.50	143.00	85.40	45.94	2.31	51.75	-2.34
143.00	143.50	84.12	43.14	2.38	54.47	-1.21
143.50	144.00	85.07	43.88	1.60	54.51	-3.87
144.00	144.50	85.01	45.36	2.30	52.34	-4.02
144.50	145.00	84.08	42.86	1.81	55.33	-5.74
145.00	145.50	85.66	44.69	2.62	52.68	-2.48
145.50	146.00	85.47	45.93	3.69	50.38	-1.49
146.00	146.50	83.93	39.15	1.64	59.21	-2.86
146.50	147.00	82.78	34.61	5.57	59.82	3.07
147.00	147.50	83.73	36.35	2.00	61.65	-1.80
147.50	148.00	84.27	39.15	1.09	59.76	4.13
148.00	148.50	85.24	41.75	1.89	56.36	2.16

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
148.50	149.00	85.74	43.51	3.24	53.24	5.73
149.00	149.50	86.05	43.97	0.63	55.40	-3.64
149.50	150.00	84.49	43.73	0.79	55.49	-1.15
150.00	150.50	85.21	41.81	2.00	56.20	-1.65
150.50	151.00	85.03	42.55	1.56	55.89	3.63
151.00	151.50	83.85	36.34	3.51	60.15	-1.61
151.50	152.00	82.76	37.13	1.80	61.07	-1.49
152.00	152.50	n/a	n/a	n/a	n/a	3.74
152.50	153.00	79.20	31.04	2.15	66.81	4.28
153.00	153.50	81.17	31.76	1.01	67.23	3.36
153.50	154.00	82.71	34.08	1.18	64.74	4.99
154.00	154.50	83.06	34.33	3.84	61.83	3.23
154.50	155.00	84.03	33.62	2.25	64.13	9.20
155.00	155.50	83.66	32.92	3.96	63.13	10.45
155.50	156.00	81.13	27.86	2.55	69.59	11.54
156.00	156.50	81.39	27.81	2.57	69.62	6.33
156.50	157.00	79.25	25.74	2.50	71.76	3.28
157.00	157.50	65.07	12.74	0.74	86.52	29.56
157.50	158.00	47.19	6.02	0.64	93.34	68.55
158.00	158.50	32.27	2.93	0.74	96.33	136.47
158.50	159.00	61.99	14.27	1.10	84.63	238.01
159.00	159.50	71.90	21.27	1.66	77.07	138.85
159.50	160.00	82.08	40.42	3.37	56.21	40.71
160.00	160.50	83.88	44.51	2.33	53.17	8.82
160.50	161.00	82.60	41.73	2.09	56.18	12.21
161.00	161.50	82.65	42.66	4.46	52.88	54.17

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
161.50	162.00	80.68	35.61	1.18	63.21	36.71
162.00	162.50	80.63	35.97	1.12	62.90	8.45
162.50	163.00	80.07	33.46	3.19	63.35	1.92
163.00	163.50	82.73	42.15	1.74	56.11	8.07
163.50	164.00	83.31	44.81	1.56	53.63	3.08
164.00	164.50	84.08	45.60	3.03	51.37	1.10
164.50	165.00	84.41	50.30	1.50	48.19	18.00
165.00	165.50	76.59	28.77	0.20	71.03	2.65
165.50	166.00	83.31	45.12	0.51	54.36	2.88
166.00	166.50	84.44	46.67	2.62	50.71	12.93
166.50	167.00	80.13	39.18	1.87	58.95	16.26
167.00	167.50	77.88	33.24	2.99	63.77	27.50
167.50	168.00	83.50	47.53	3.36	49.11	7.58
168.00	168.50	82.49	45.66	0.41	53.93	5.24
168.50	169.00	79.36	36.68	2.11	61.21	4.91
169.00	169.50	81.59	43.38	3.29	53.33	1.02
169.50	170.00	82.76	45.94	2.85	51.21	-1.41
170.00	170.50	79.02	26.83	2.09	71.08	6.72
170.50	171.00	82.94	47.07	0.82	52.11	26.05
171.00	171.50	81.68	40.80	2.68	56.52	16.03
171.50	172.00	83.52	49.33	3.10	47.57	11.23
172.00	172.50	80.90	42.94	2.53	54.53	-4.69
172.50	173.00	83.15	47.61	1.44	50.95	4.62
173.00	173.50	83.71	48.33	3.85	47.82	9.61
173.50	174.00	84.39	49.97	2.70	47.32	-1.27
174.00	174.50	83.92	48.37	2.80	48.84	-1.84

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
174.50	175.00	83.96	48.42	2.72	48.86	-1.19
175.00	175.50	83.35	45.36	2.67	51.97	-1.93
175.50	176.00	84.18	47.86	2.24	49.90	-1.20
176.00	176.50	83.79	48.62	3.66	47.72	-1.95
176.50	177.00	79.91	38.63	2.37	58.99	5.56
177.00	177.50	n/a	n/a	n/a	n/a	24.14
177.50	178.00	75.30	26.66	1.44	71.90	11.06
178.00	178.50	74.60	24.94	1.20	73.86	49.18
178.50	179.00	82.86	44.45	3.77	51.77	24.89
179.00	179.50	84.93	46.75	2.64	50.62	2.00
179.50	180.00	83.92	45.76	1.84	52.40	1.11
180.00	180.50	83.61	47.05	2.98	49.96	10.60
180.50	181.00	75.45	28.29	2.00	69.71	1.09
181.00	181.50	83.46	46.86	2.58	50.56	31.96
181.50	182.00	80.24	40.19	3.46	56.35	8.92
182.00	182.50	83.01	47.21	2.17	50.62	-2.60
182.50	183.00	83.49	48.72	2.18	49.10	-1.05
183.00	183.50	84.05	49.47	1.97	48.56	6.21
183.50	184.00	81.94	44.03	2.18	53.79	1.53
184.00	184.50	83.15	48.73	2.76	48.51	2.03
184.50	185.00	83.60	51.62	1.74	46.65	6.16
185.00	185.50	83.73	49.50	2.24	48.26	7.07
185.50	186.00	82.59	46.28	3.02	50.70	3.73
186.00	186.50	83.77	50.66	2.55	46.79	-1.67
186.50	187.00	83.22	47.23	6.21	46.56	1.32
187.00	187.50	82.53	48.03	3.53	48.44	1.19

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
187.50	188.00	82.72	51.29	3.11	45.60	13.63
188.00	188.50	82.45	51.47	2.66	45.87	5.74
188.50	189.00	83.38	56.34	3.48	40.18	1.03
189.00	189.50	83.55	60.32	3.07	36.61	-3.67
189.50	190.00	84.44	62.71	2.34	34.96	-4.62
190.00	190.50	84.72	57.02	2.94	40.04	-3.37
190.50	191.00	84.52	51.92	2.34	45.74	-2.06
191.00	191.50	n/a	n/a	n/a	n/a	4.79
191.50	192.00	84.03	52.51	1.92	45.58	1.27
192.00	192.50	83.63	53.11	1.69	45.20	-2.10
192.50	193.00	83.60	52.94	2.48	44.58	3.74
193.00	193.50	83.46	52.46	2.00	45.54	1.70
193.50	194.00	79.21	42.35	2.12	55.53	3.23
194.00	194.50	82.13	47.11	1.75	51.14	4.63
194.50	195.00	82.48	49.95	0.20	49.85	5.24
195.00	195.50	83.55	50.33	1.91	47.75	5.87
195.50	196.00	83.39	48.07	5.04	46.89	7.28
196.00	196.50	83.51	50.29	1.13	48.58	-1.52
196.50	197.00	83.20	52.31	1.63	46.06	1.54
197.00	197.50	83.93	53.00	1.87	45.13	1.31
197.50	198.00	83.57	53.29	1.96	44.75	3.18
198.00	198.50	83.88	52.81	2.05	45.14	-1.77
198.50	199.00	83.34	49.54	0.27	50.19	6.79
199.00	199.50	83.36	49.68	2.18	48.14	1.23
199.50	200.00	81.67	49.25	1.27	49.48	2.02
200.00	200.50	82.90	49.66	1.97	48.38	1.10

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
200.50	201.00	83.00	51.63	2.22	46.14	1.47
201.00	201.50	83.20	51.50	2.13	46.37	2.08
201.50	202.00	84.10	55.82	1.73	42.44	2.78
202.00	202.50	n/a	n/a	n/a	n/a	-1.73
202.50	203.00	84.61	56.28	2.29	41.43	-1.10
203.00	203.50	83.93	57.69	1.73	40.58	-4.21
203.50	204.00	83.70	55.84	1.84	42.32	-4.81
204.00	204.50	82.51	50.80	2.01	47.19	-3.10
204.50	205.00	83.32	53.43	1.36	45.21	-4.33
205.00	205.50	84.07	54.62	2.15	43.23	-4.43
205.50	206.00	84.30	53.22	2.44	44.33	-3.09
206.00	206.50	84.49	53.87	2.21	43.92	-2.32
206.50	207.00	84.03	56.04	1.52	42.44	-4.41
207.00	207.50	84.03	51.27	2.76	45.96	-5.96
207.50	208.00	85.15	53.62	3.77	42.61	-6.29
208.00	208.50	84.18	53.10	5.34	41.56	-2.64
208.50	209.00	84.76	54.00	2.53	43.47	-5.71
209.00	209.50	82.47	46.61	1.47	51.91	-2.89
209.50	210.00	85.76	54.39	2.65	42.96	-4.58
210.00	210.50	86.27	52.39	2.49	45.12	-7.49
210.50	211.00	86.92	50.92	2.91	46.18	-8.94
211.00	211.50	86.22	53.09	2.52	44.38	-8.98
211.50	212.00	85.46	54.46	2.84	42.70	-8.83
212.00	212.50	85.23	54.67	1.88	43.45	-5.80
212.50	213.00	85.87	54.06	4.09	41.85	-5.08
213.00	213.50	86.19	55.71	2.34	41.95	-9.14

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
213.50	214.00	86.29	58.94	1.57	39.49	-2.97
214.00	214.50	85.45	59.36	1.88	38.75	-8.43
214.50	215.00	85.84	60.05	1.88	38.07	-6.32
215.00	215.50	85.95	58.24	2.39	39.37	-9.93
215.50	216.00	85.96	57.84	2.83	39.33	-2.33
216.00	216.50	85.76	55.56	2.06	42.38	-5.62
216.50	217.00	86.25	56.08	1.15	42.77	-9.22
217.00	217.50	86.18	56.52	2.27	41.20	-9.21
217.50	218.00	86.23	56.60	1.62	41.78	-5.00
218.00	218.50	85.88	56.68	0.68	42.64	-6.02
218.50	219.00	86.12	53.60	3.66	42.74	-6.11
219.00	219.50	86.04	54.53	2.45	43.03	-8.04
219.50	220.00	86.66	52.28	2.82	44.90	-6.34
220.00	220.50	87.54	52.85	1.89	45.26	-4.70
220.50	221.00	85.83	54.74	2.33	42.93	-8.83
221.00	221.50	85.39	54.64	3.18	42.18	-9.22
221.50	222.00	85.58	55.13	3.58	41.29	-3.86
222.00	222.50	85.17	53.29	2.26	44.45	-4.10
222.50	223.00	85.55	55.54	2.08	42.38	-3.55
223.00	223.50	85.41	57.59	0.98	41.43	-5.69
223.50	224.00	85.85	58.52	2.68	38.79	-8.56
224.00	224.50	84.99	57.35	2.02	40.63	-7.52
224.50	225.00	86.10	56.96	2.82	40.22	-8.32
225.00	225.50	85.53	54.73	1.01	44.26	-6.15
225.50	226.00	84.64	53.34	3.19	43.47	-1.46
226.00	226.50	85.22	52.66	1.95	45.39	-9.28

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
226.50	227.00	83.97	51.18	3.21	45.61	-2.46
227.00	227.50	n/a	n/a	n/a	n/a	-5.78
227.50	228.00	85.32	53.36	4.10	42.55	-3.10
228.00	228.50	85.60	52.54	2.61	44.85	3.28
228.50	229.00	85.33	54.04	3.09	42.87	-8.36
229.00	229.50	85.20	55.09	2.64	42.26	-7.89
229.50	230.00	85.59	53.08	2.71	44.21	-6.80
230.00	230.50	85.54	55.40	3.53	41.07	-3.99
230.50	231.00	85.53	55.14	3.38	41.48	-4.67
231.00	231.50	85.06	54.12	2.69	43.19	-7.30
231.50	232.00	85.66	54.32	2.28	43.40	-5.25
232.00	232.50	85.31	54.33	3.95	41.72	-5.54
232.50	233.00	84.55	50.41	3.52	46.07	-5.66
233.00	233.50	85.13	52.22	2.28	45.50	-7.31
233.50	234.00	84.08	52.97	2.61	44.43	-6.40
234.00	234.50	84.38	52.65	3.57	43.78	-3.11
234.50	235.00	84.09	52.82	2.64	44.54	-6.64
235.00	235.50	82.56	47.78	3.09	49.12	-6.18
235.50	236.00	83.45	52.58	3.46	43.96	-7.09
236.00	236.50	83.70	50.46	2.81	46.73	-2.12
236.50	237.00	83.41	49.88	3.25	46.87	-1.51
237.00	237.50	n/a	n/a	n/a	n/a	-3.02
237.50	238.00	83.74	52.84	4.11	43.06	-3.28
238.00	238.50	83.92	52.27	3.63	44.10	-3.34
238.50	239.00	83.86	53.29	2.60	44.11	-2.88
239.00	239.50	83.84	52.55	3.44	44.01	3.51

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
239.50	240.00	82.89	50.63	2.92	46.45	2.21
240.00	240.50	83.04	50.80	2.86	46.34	5.55
240.50	241.00	83.45	51.77	2.80	45.43	3.30
241.00	241.50	83.91	54.71	2.75	42.54	8.89
241.50	242.00	83.78	50.59	3.46	45.95	1.65
242.00	242.50	84.68	49.69	1.00	49.31	7.50
242.50	243.00	82.89	47.96	1.71	50.33	2.36
243.00	243.50	n/a	n/a	n/a	n/a	-1.21
243.50	244.00	83.41	47.68	1.18	51.14	-2.78
244.00	244.50	82.81	47.20	1.84	50.96	-4.07
244.50	245.00	81.25	44.77	2.60	52.63	-1.96
245.00	245.50	81.16	43.35	1.98	54.67	-2.35
245.50	246.00	82.76	48.16	1.59	50.25	2.80
246.00	246.50	83.35	47.13	2.82	50.05	2.71
246.50	247.00	82.93	47.91	2.14	49.95	3.50
247.00	247.50	83.09	47.87	2.12	50.01	1.24
247.50	248.00	81.87	45.00	2.27	52.73	4.47
248.00	248.50	82.37	47.94	1.29	50.77	1.83
248.50	249.00	83.03	46.91	2.92	50.16	1.45
249.00	249.50	82.38	44.41	2.85	52.74	3.71
249.50	250.00	80.79	40.47	2.25	57.28	6.48
250.00	250.50	81.99	42.53	1.40	56.07	6.48
250.50	251.00	83.08	45.69	1.35	52.96	1.68
251.00	251.50	83.45	45.93	2.07	51.99	2.56
251.50	252.00	82.94	47.24	2.05	50.70	1.56
252.00	252.50	n/a	n/a	n/a	n/a	1.99

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
252.50	253.00	83.53	49.33	1.91	48.77	1.14
253.00	253.50	84.45	51.46	1.76	46.77	-2.61
253.50	254.00	83.74	51.61	2.36	46.03	1.05
254.00	254.50	84.01	52.39	1.79	45.82	-2.49
254.50	255.00	84.71	50.56	1.27	48.17	-2.88
255.00	255.50	84.37	49.89	1.75	48.37	-1.13
255.50	256.00	84.92	50.86	2.42	46.72	-3.62
256.00	256.50	83.36	48.74	2.70	48.56	-6.54
256.50	257.00	82.99	48.69	2.52	48.79	-3.92
257.00	257.50	83.30	50.22	3.82	45.96	-1.44
257.50	258.00	82.77	49.89	3.12	46.99	-3.80
258.00	258.50	83.18	50.51	3.20	46.29	-1.74
258.50	259.00	83.17	48.48	4.77	46.75	9.45
259.00	259.50	82.66	47.62	0.23	52.15	1.29
259.50	260.00	82.10	43.25	1.41	55.34	3.12
260.00	260.50	n/a	n/a	n/a	n/a	8.97
260.50	261.00	n/a	n/a	n/a	n/a	8.48
261.00	261.50	n/a	n/a	n/a	n/a	2.52
261.50	262.00	85.64	47.50	2.64	49.86	7.91
262.00	262.50	84.90	46.27	2.90	50.83	5.53
262.50	263.00	83.53	44.55	3.24	52.20	1.63
263.00	263.50	85.14	46.28	1.61	52.11	5.31
263.50	264.00	84.56	44.85	2.70	52.45	4.11
264.00	264.50	84.10	44.88	2.78	52.33	10.58
264.50	265.00	84.89	43.13	2.04	54.82	1.05
265.00	265.50	83.93	42.44	2.13	55.43	1.25

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
265.50	266.00	83.00	45.45	1.37	53.17	1.94
266.00	266.50	82.90	43.81	1.91	54.28	4.12
266.50	267.00	83.43	45.96	0.85	53.19	1.50
267.00	267.50	82.72	43.81	2.22	53.96	5.83
267.50	268.00	82.68	45.05	4.83	50.12	2.49
268.00	268.50	83.66	47.10	2.76	50.14	-1.12
268.50	269.00	81.95	43.88	2.34	53.77	1.84
269.00	269.50	82.81	48.39	1.83	49.78	2.14
269.50	270.00	83.21	46.67	0.74	52.60	-2.06
270.00	270.50	83.24	48.24	2.32	49.45	-3.12
270.50	271.00	82.75	51.20	0.71	48.09	-3.31
271.00	271.50	83.20	49.38	2.33	48.29	-3.05
271.50	272.00	82.94	48.32	2.98	48.70	-1.33
272.00	272.50	83.04	48.29	2.37	49.34	1.43
272.50	273.00	83.96	53.27	2.35	44.38	-2.19
273.00	273.50	83.84	49.79	2.98	47.23	-2.02
273.50	274.00	83.83	49.27	1.71	49.02	-2.04
274.00	274.50	84.26	50.56	1.87	47.56	-2.78
274.50	275.00	82.58	47.11	2.22	50.67	-5.47
275.00	275.50	84.27	49.82	1.38	48.80	-2.92
275.50	276.00	83.88	51.28	1.25	47.47	-6.38
276.00	276.50	84.19	51.93	2.69	45.38	-1.32
276.50	277.00	84.16	50.91	2.16	46.93	-8.04
277.00	277.50	n/a	n/a	n/a	n/a	-4.49
277.50	278.00	82.85	50.67	3.79	45.54	4.38
278.00	278.50	83.89	52.57	1.19	46.25	1.87

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
278.50	279.00	83.42	47.76	1.92	50.32	-1.01
279.00	279.50	83.31	46.23	2.59	51.18	-1.52
279.50	280.00	83.13	47.08	0.49	52.43	1.86
280.00	280.50	83.40	42.53	1.45	56.02	4.74
280.50	281.00	81.92	41.70	1.23	57.08	4.23
281.00	281.50	80.08	37.33	2.23	60.44	-1.78
281.50	282.00	81.92	43.76	2.02	54.21	5.06
282.00	282.50	81.28	42.59	1.70	55.71	2.11
282.50	283.00	81.99	43.95	0.45	55.60	3.99
283.00	283.50	83.77	47.99	1.50	50.51	4.78
283.50	284.00	n/a	n/a	n/a	n/a	-2.97
284.00	284.50	82.65	45.80	1.68	52.52	-5.04
284.50	285.00	83.77	50.50	0.32	49.17	1.13
285.00	285.50	84.19	51.59	2.91	45.50	-6.17
285.50	286.00	84.12	49.56	2.32	48.12	-6.61
286.00	286.50	83.47	49.24	2.39	48.37	-9.77
286.50	287.00	82.27	49.18	2.82	47.99	-8.09
287.00	287.50	84.11	46.81	2.73	50.46	-8.31
287.50	288.00	84.47	48.62	2.96	48.42	-6.50
288.00	288.50	84.92	46.12	4.74	49.14	-3.71
288.50	289.00	83.83	47.01	0.93	52.06	-7.92
289.00	289.50	84.87	48.67	1.81	49.52	-5.51
289.50	290.00	85.62	51.04	1.23	47.73	-4.57
290.00	290.50	83.71	47.93	2.16	49.90	-7.68
290.50	291.00	84.44	50.19	0.66	49.16	-2.68
291.00	291.50	83.23	50.49	1.48	48.03	-2.81

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
291.50	292.00	83.31	49.83	1.88	48.29	-5.56
292.00	292.50	82.69	45.45	1.00	53.55	-5.47
292.50	293.00	82.93	44.71	1.25	54.04	-5.55
293.00	293.50	83.46	46.28	1.81	51.91	-4.20
293.50	294.00	85.04	51.64	2.23	46.13	-5.96
294.00	294.50	84.19	48.25	1.91	49.85	-3.98
294.50	295.00	85.67	56.23	1.68	42.10	-4.41
295.00	295.50	82.09	45.54	1.05	53.41	-7.21
295.50	296.00	83.74	49.38	1.91	48.72	-2.20
296.00	296.50	83.76	51.57	2.13	46.30	-7.54
296.50	297.00	83.89	52.30	3.98	43.72	-7.03
297.00	297.50	81.44	51.72	1.98	46.30	-9.57
297.50	298.00	78.81	50.62	1.68	47.70	-9.88
298.00	298.50	81.35	50.40	1.84	47.76	1.88
298.50	299.00	81.65	51.77	0.78	47.44	1.15
299.00	299.50	83.11	51.97	2.13	45.90	-6.13
299.50	300.00	n/a	n/a	n/a	n/a	-7.55
300.00	300.50	81.19	48.80	0.50	50.70	-7.82
300.50	301.00	81.13	50.86	2.09	47.05	1.15
301.00	301.50	82.50	50.65	1.41	47.94	-1.05
301.50	302.00	n/a	n/a	n/a	n/a	-8.07
302.00	302.50	n/a	n/a	n/a	n/a	-5.46
302.50	303.00	83.43	49.12	1.89	48.99	-8.45
303.00	303.50	80.71	48.89	1.29	49.82	-5.79
303.50	304.00	83.69	47.26	1.98	50.75	-8.91
304.00	304.50	81.42	46.68	1.96	51.36	-5.07

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
304.50	305.00	77.46	42.59	1.56	55.85	2.50
305.00	305.50	80.72	43.13	2.28	54.58	-7.43
305.50	306.00	82.04	46.02	2.69	51.29	-6.43
306.00	306.50	79.75	44.60	2.78	52.63	-5.57
306.50	307.00	79.80	48.03	2.18	49.80	-4.95
307.00	307.50	80.32	46.74	2.35	50.91	1.91
307.50	308.00	79.94	43.62	1.45	54.93	-6.66
308.00	308.50	79.99	43.30	2.49	54.21	-4.83
308.50	309.00	78.59	43.52	1.24	55.24	-8.78
309.00	309.50	78.34	44.48	2.08	53.44	-7.88
309.50	310.00	77.23	45.10	2.39	52.51	-4.59
310.00	310.50	79.56	44.82	2.43	52.75	1.77
310.50	311.00	81.33	46.07	1.80	52.13	-5.41
311.00	311.50	80.56	47.16	2.35	50.50	-9.25
311.50	312.00	79.08	41.21	0.44	58.35	-4.59
312.00	312.50	n/a	n/a	n/a	n/a	1.22
312.50	313.00	80.32	44.71	2.26	53.03	6.55
313.00	313.50	80.93	45.09	2.20	52.71	2.85
313.50	314.00	80.49	44.75	2.57	52.68	-2.04
314.00	314.50	81.32	46.40	2.54	51.06	-7.74
314.50	315.00	82.16	48.04	1.61	50.35	-8.70
315.00	315.50	80.76	46.75	2.02	51.23	-7.07
315.50	316.00	82.41	44.80	3.77	51.43	-4.58
316.00	316.50	81.12	44.75	2.34	52.91	-1.84
316.50	317.00	80.40	43.51	2.83	53.66	-4.94
317.00	317.50	80.90	45.05	1.26	53.69	2.13

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
317.50	318.00	81.90	45.78	2.19	52.03	-6.39
318.00	318.50	83.19	45.51	2.56	51.93	-7.38
318.50	319.00	81.81	45.57	2.41	52.02	-6.91
319.00	319.50	82.75	47.58	1.56	50.86	-9.62
319.50	320.00	81.88	46.98	1.19	51.83	-2.37
320.00	320.50	81.25	50.68	1.59	47.73	-4.47
320.50	321.00	83.05	52.18	1.53	46.29	-8.52
321.00	321.50	81.43	48.44	1.64	49.92	-9.89
321.50	322.00	82.46	47.73	1.35	50.92	-6.67
322.00	322.50	81.39	47.09	2.54	50.37	-6.00
322.50	323.00	80.24	41.52	3.28	55.21	-3.85
323.00	323.50	n/a	n/a	n/a	n/a	-7.51
323.50	324.00	81.41	43.81	1.47	54.71	-7.38
324.00	324.50	81.56	45.89	1.92	52.20	-6.96
324.50	325.00	80.92	43.69	2.20	54.11	-4.09
325.00	325.50	78.87	36.34	0.40	63.26	-6.42
325.50	326.00	77.51	34.19	1.53	64.28	-1.30
326.00	326.50	77.97	38.79	1.14	60.07	-5.94
326.50	327.00	78.82	39.52	1.51	58.97	-1.54
327.00	327.50	n/a	n/a	n/a	n/a	-4.46
327.50	328.00	80.91	42.17	1.62	56.21	-6.88
328.00	328.50	82.09	46.75	1.92	51.33	-3.36
328.50	329.00	81.97	46.19	1.92	51.90	-4.01
329.00	329.50	80.36	44.83	1.78	53.39	-7.39
329.50	330.00	81.35	42.40	2.95	54.65	-3.75
330.00	330.50	82.39	42.32	1.76	55.92	-8.74

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
330.50	331.00	81.08	44.04	1.01	54.94	-5.99
331.00	331.50	81.99	45.49	3.21	51.30	-8.99
331.50	332.00	82.01	46.61	1.74	51.65	-6.30
332.00	332.50	n/a	n/a	n/a	n/a	-5.92
332.50	333.00	81.07	45.01	3.23	51.76	-8.65
333.00	333.50	82.28	48.40	2.07	49.52	-3.55
333.50	334.00	82.37	48.88	2.70	48.42	-4.62
334.00	334.50	82.84	49.50	1.76	48.74	-3.65
334.50	335.00	82.11	47.24	1.75	51.01	-8.42
335.00	335.50	82.34	49.32	1.98	48.70	-7.26
335.50	336.00	82.31	50.42	1.68	47.89	-9.63
336.00	336.50	n/a	n/a	n/a	n/a	-8.41
336.50	337.00	81.17	51.53	1.95	46.51	-6.08
337.00	337.50	81.51	50.45	1.60	47.95	-9.02
337.50	338.00	81.70	49.64	1.80	48.56	-5.66
338.00	338.50	81.80	51.24	1.68	47.08	-9.93
338.50	339.00	82.62	51.39	1.33	47.28	-8.47
339.00	339.50	n/a	n/a	n/a	n/a	-8.49
339.50	340.00	81.81	50.02	2.13	47.85	-9.15
340.00	340.50	80.76	49.31	1.87	48.82	-9.29
340.50	341.00	81.37	47.87	2.33	49.80	-8.57
341.00	341.50	81.09	47.21	3.10	49.69	-9.58
341.50	342.00	81.32	47.05	2.68	50.28	-8.82
342.00	342.50	80.35	47.58	1.81	50.61	-3.43
342.50	343.00	81.16	47.58	2.19	50.23	-9.84
343.00	343.50	82.55	50.03	1.84	48.13	-5.10

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
343.50	344.00	80.38	47.96	1.18	50.86	-3.70
344.00	344.50	83.24	58.32	2.26	39.41	-5.38
344.50	345.00	83.62	59.00	2.62	38.38	-8.06
345.00	345.50	82.16	56.34	1.70	41.96	-3.56
345.50	346.00	82.02	50.06	2.36	47.58	-8.23
346.00	346.50	83.43	52.01	2.20	45.79	2.61
346.50	347.00	83.78	55.21	1.99	42.80	1.80
347.00	347.50	82.42	46.41	3.31	50.28	-6.47
347.50	348.00	83.37	47.73	3.29	48.98	-8.40
348.00	348.50	83.16	51.70	2.95	45.35	-4.71
348.50	349.00	82.08	51.95	1.70	46.35	-6.90
349.00	349.50	80.02	47.25	2.16	50.59	-7.50
349.50	350.00	81.88	50.65	3.14	46.20	-6.38
350.00	350.50	83.89	53.52	2.85	43.63	-7.02
350.50	351.00	82.75	55.46	2.81	41.73	-4.67
351.00	351.50	81.57	53.94	2.75	43.31	-8.90
351.50	352.00	81.20	51.81	1.56	46.63	-9.46
352.00	352.50	n/a	n/a	n/a	n/a	-8.15
352.50	353.00	81.30	53.16	1.89	44.95	-3.59
353.00	353.50	80.76	54.02	2.38	43.60	-2.62
353.50	354.00	85.13	54.33	1.96	43.71	-3.96
354.00	354.50	82.90	57.96	2.13	39.91	-8.76
354.50	355.00	82.67	54.44	2.64	42.92	-2.12
355.00	355.50	85.00	59.20	1.46	39.34	-10.89
355.50	356.00	85.12	59.65	3.01	37.34	-11.27
356.00	356.50	85.10	62.89	3.15	33.96	-12.98

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
356.50	357.00	83.47	59.51	4.19	36.30	-7.66
357.00	357.50	83.81	62.75	1.56	35.69	-11.63
357.50	358.00	84.69	63.34	2.36	34.30	-13.62
358.00	358.50	84.38	59.72	2.01	38.27	-12.45
358.50	359.00	83.80	59.52	4.09	36.40	-13.96
359.00	359.50	84.57	57.94	2.16	39.90	-10.46
359.50	360.00	83.80	58.68	3.03	38.29	-9.16
360.00	360.50	84.50	60.43	1.73	37.84	-12.78
360.50	361.00	84.26	61.31	3.20	35.49	-11.03
361.00	361.50	84.27	60.53	3.53	35.94	-12.96
361.50	362.00	84.53	62.42	2.04	35.54	-11.88
362.00	362.50	84.29	65.58	0.87	33.55	-12.88
362.50	363.00	84.90	63.81	1.25	34.94	-13.34
363.00	363.50	84.56	65.22	0.77	34.02	-14.08
363.50	364.00	85.46	68.30	0.47	31.23	-13.56
364.00	364.50	85.57	68.36	0.41	31.23	-11.61
364.50	365.00	85.62	69.07	0.21	30.71	-14.31
365.00	365.50	86.19	70.17	1.45	28.37	-13.16
365.50	366.00	86.65	66.79	0.62	32.59	-11.02
366.00	366.50	85.53	65.11	0.50	34.39	-12.94
366.50	367.00	84.62	65.25	0.43	34.32	-11.00
367.00	367.50	81.98	65.79	0.61	33.60	-2.67
367.50	368.00	84.51	64.61	1.26	34.13	-6.09
368.00	368.50	84.17	60.69	0.92	38.39	-12.38
368.50	369.00	84.66	62.46	2.38	35.16	-12.05
369.00	369.50	82.97	60.16	1.39	38.46	-11.26

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
369.50	370.00	83.40	56.40	0.18	43.42	-4.04
370.00	370.50	82.62	53.03	1.03	45.94	-10.14
370.50	371.00	83.06	54.09	1.08	44.83	-8.69
371.00	371.50	80.37	46.43	1.89	51.68	-8.37
371.50	372.00	85.01	59.87	1.22	38.90	-12.15
372.00	372.50	84.55	59.45	1.11	39.44	-12.38
372.50	373.00	85.06	61.30	0.56	38.14	-11.11
373.00	373.50	83.86	56.43	1.07	42.50	-10.69
373.50	374.00	83.54	54.08	1.04	44.88	-6.99
374.00	374.50	84.33	56.60	1.29	42.12	-9.04
374.50	375.00	83.73	55.66	1.10	43.24	-8.57
375.00	375.50	82.25	51.09	1.06	47.84	-10.33
375.50	376.00	83.44	56.07	0.54	43.39	-13.02
376.00	376.50	83.48	55.30	1.09	43.61	-11.59
376.50	377.00	83.52	56.13	1.24	42.64	-9.39
377.00	377.50	n/a	n/a	n/a	n/a	-11.44
377.50	378.00	82.45	51.56	1.33	47.11	-8.47
378.00	378.50	82.50	49.37	1.50	49.13	-9.68
378.50	379.00	n/a	n/a	n/a	n/a	-9.68
379.00	379.50	83.70	56.23	1.95	41.82	-12.77
379.50	380.00	84.18	58.35	0.47	41.18	-13.50
380.00	380.50	84.21	58.13	1.23	40.64	-12.83
380.50	381.00	84.08	54.69	2.13	43.18	-10.21
381.00	381.50	83.50	53.30	1.10	45.60	-13.13
381.50	382.00	83.53	51.59	1.06	47.35	-10.12
382.00	382.50	n/a	n/a	n/a	n/a	-4.72

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
382.50	383.00	n/a	n/a	n/a	n/a	-2.53
383.00	383.50	84.28	56.58	1.92	41.50	-11.71
383.50	384.00	85.57	62.39	1.61	36.00	-11.40
384.00	384.50	82.25	48.36	1.30	50.35	-9.84
384.50	385.00	84.39	58.94	0.90	40.16	-9.03
385.00	385.50	82.31	53.40	0.86	45.74	1.96
385.50	386.00	81.15	50.80	0.96	48.25	-6.88
386.00	386.50	82.80	55.40	0.80	43.80	-9.90
386.50	387.00	82.75	56.98	0.98	42.04	-8.92
387.00	387.50	82.78	58.42	1.43	40.15	-9.17
387.50	388.00	83.83	59.19	1.14	39.66	-10.98
388.00	388.50	84.74	64.14	0.56	35.30	-11.34
388.50	389.00	84.55	63.80	0.90	35.30	-11.04
389.00	389.50	85.30	64.19	1.31	34.50	-10.78
389.50	390.00	85.37	64.17	1.12	34.71	-12.87
390.00	390.50	84.54	59.61	1.26	39.13	-11.46
390.50	391.00	85.09	62.85	1.97	35.17	-11.93
391.00	391.50	84.74	59.50	0.78	39.72	-10.32
391.50	392.00	83.84	56.23	1.65	42.12	-10.18
392.00	392.50	82.44	62.48	0.54	36.97	-1.16
392.50	393.00	84.43	60.63	0.13	39.23	-3.76
393.00	393.50	84.07	59.35	1.56	39.09	-11.27
393.50	394.00	84.05	60.34	0.46	39.21	-11.40
394.00	394.50	83.80	59.40	2.00	38.60	-11.26
394.50	395.00	82.60	52.99	1.36	45.65	-10.39
395.00	395.50	84.21	58.43	1.85	39.72	-12.00

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
395.50	396.00	82.30	53.98	1.46	44.56	-12.48
396.00	396.50	82.75	56.97	1.43	41.61	-9.72
396.50	397.00	84.44	59.03	0.82	40.15	-13.14
397.00	397.50	83.83	59.28	1.62	39.09	-9.13
397.50	398.00	83.68	58.37	0.51	41.12	-7.37
398.00	398.50	82.21	55.67	4.72	39.60	-6.91
398.50	399.00	83.43	57.21	1.23	41.55	-3.53
399.00	399.50	82.67	53.57	1.44	45.00	-1.21
399.50	400.00	78.15	48.29	0.62	51.09	-3.69
400.00	400.50	84.86	57.83	1.27	40.91	-2.09
400.50	401.00	85.79	62.00	0.69	37.31	-9.92
401.00	401.50	84.63	59.02	1.55	39.43	-7.86
401.50	402.00	83.92	54.38	2.89	42.74	-3.88
402.00	402.50	n/a	n/a	n/a	n/a	-8.88
402.50	403.00	82.76	53.55	0.82	45.63	-3.80
403.00	403.50	80.82	47.47	1.23	51.29	-4.99
403.50	404.00	81.14	46.72	1.43	51.85	1.81
404.00	404.50	83.06	53.88	1.82	44.30	-4.88
404.50	405.00	83.88	56.80	2.08	41.12	-6.07
405.00	405.50	85.97	66.07	2.23	31.70	-4.83
405.50	406.00	n/a	n/a	n/a	n/a	-8.31
406.00	406.50	86.33	65.63	0.68	33.68	-5.64
406.50	407.00	85.87	66.71	0.64	32.65	-8.23
407.00	407.50	85.75	66.04	1.71	32.25	-3.96
407.50	408.00	85.41	64.90	1.30	33.80	-9.69
408.00	408.50	85.60	67.01	2.05	30.94	-2.88

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
408.50	409.00	85.11	62.78	1.94	35.28	-1.25
409.00	409.50	85.91	62.88	1.88	35.25	-8.72
409.50	410.00	85.88	64.55	0.62	34.83	-3.40
410.00	410.50	86.45	63.86	0.73	35.41	-6.47
410.50	411.00	85.49	60.80	1.05	38.15	-8.03
411.00	411.50	86.23	64.74	1.47	33.79	-6.50
411.50	412.00	86.20	65.30	1.18	33.52	-8.12
412.00	412.50	85.83	62.77	2.19	35.04	-8.29
412.50	413.00	85.15	59.86	1.63	38.50	-4.42
413.00	413.50	84.13	55.81	1.92	42.27	-3.26
413.50	414.00	83.80	52.76	3.67	43.57	8.95
414.00	414.50	83.19	57.18	0.55	42.27	-3.39
414.50	415.00	83.87	62.25	0.84	36.91	-3.69
415.00	415.50	84.82	58.16	1.78	40.05	-3.07
415.50	416.00	84.87	61.32	1.43	37.24	-7.01
416.00	416.50	85.79	58.98	2.58	38.44	-5.64
416.50	417.00	84.64	52.70	1.54	45.76	-6.72
417.00	417.50	84.49	53.49	1.73	44.79	-7.88
417.50	418.00	84.97	54.80	1.10	44.09	-8.94
418.00	418.50	84.36	52.59	2.38	45.03	-8.51
418.50	419.00	85.58	55.17	1.62	43.20	-8.69
419.00	419.50	85.29	57.32	1.98	40.70	-9.28
419.50	420.00	85.07	55.38	1.72	42.90	-7.23
420.00	420.50	84.49	51.83	1.17	46.99	-1.98
420.50	421.00	84.58	52.92	1.09	45.99	-8.48
421.00	421.50	84.75	53.41	1.88	44.71	-3.15

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
421.50	422.00	84.97	55.20	1.92	42.88	-6.13
422.00	422.50	84.72	55.60	1.88	42.52	-5.81
422.50	423.00	85.19	57.39	1.97	40.64	-5.86
423.00	423.50	85.00	59.87	0.57	39.56	-6.36
423.50	424.00	83.90	56.10	2.33	41.57	-4.88
424.00	424.50	83.98	52.64	1.72	45.65	-7.98
424.50	425.00	84.60	56.36	2.02	41.63	-5.57
425.00	425.50	85.05	58.56	2.55	38.89	-2.28
425.50	426.00	84.59	56.43	2.28	41.29	-6.77
426.00	426.50	84.42	55.85	3.16	40.99	-3.74
426.50	427.00	84.15	56.75	1.27	41.98	-5.49
427.00	427.50	n/a	n/a	n/a	n/a	-1.36
427.50	428.00	84.32	55.08	2.17	42.75	-3.60
428.00	428.50	83.88	52.70	1.97	45.33	-2.21
428.50	429.00	n/a	n/a	n/a	n/a	-4.63
429.00	429.50	84.66	55.82	3.58	40.60	-6.60
429.50	430.00	84.70	54.09	3.23	42.68	-3.89
430.00	430.50	85.08	55.88	2.78	41.34	-4.78
430.50	431.00	85.01	58.44	2.87	38.69	-2.86
431.00	431.50	84.72	56.57	2.81	40.62	-2.64
431.50	432.00	83.41	50.03	1.86	48.11	-2.66
432.00	432.50	83.03	49.38	2.05	48.57	-1.01
432.50	433.00	83.79	50.73	3.50	45.77	-3.05
433.00	433.50	84.25	50.75	2.24	47.01	-3.01
433.50	434.00	83.51	46.35	3.86	49.79	-5.17
434.00	434.50	81.71	41.75	3.61	54.64	-2.25

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
434.50	435.00	81.12	39.64	3.72	56.64	-3.54
435.00	435.50	83.38	42.68	4.30	53.02	-1.62
435.50	436.00	81.10	47.42	2.76	49.82	-2.97
436.00	436.50	83.04	53.58	2.70	43.72	3.55
436.50	437.00	84.87	57.48	3.10	39.42	-5.33
437.00	437.50	84.50	59.82	0.20	39.98	-5.81
437.50	438.00	85.85	59.56	1.34	39.10	-6.48
438.00	438.50	n/a	n/a	n/a	n/a	-9.47
438.50	439.00	n/a	n/a	n/a	n/a	-9.26
439.00	439.50	84.78	57.55	1.47	40.98	-9.07
439.50	440.00	84.07	55.41	0.85	43.74	-8.62
440.00	440.50	83.66	54.10	1.72	44.19	-5.61
440.50	441.00	81.99	51.54	1.00	47.46	-2.73
441.00	441.50	83.73	53.89	1.37	44.74	-1.69
441.50	442.00	83.80	53.72	1.55	44.73	-2.00
442.00	442.50	83.38	51.91	1.61	46.48	-5.08
442.50	443.00	82.97	51.68	1.09	47.23	3.19
443.00	443.50	82.97	53.20	1.48	45.32	1.19
443.50	444.00	83.46	58.23	1.30	40.47	2.53
444.00	444.50	83.35	59.41	1.03	39.56	2.22
444.50	445.00	84.58	64.13	0.94	34.93	1.34
445.00	445.50	85.31	67.96	0.20	31.83	-1.37
445.50	446.00	85.92	67.40	0.69	31.90	-1.56
446.00	446.50	85.40	61.98	0.97	37.05	-2.28
446.50	447.00	84.99	58.55	2.16	39.29	-2.96
447.00	447.50	85.77	61.66	1.40	36.94	-3.24

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
447.50	448.00	84.65	57.70	0.75	41.55	-2.12
448.00	448.50	84.34	56.55	1.46	41.99	-4.36
448.50	449.00	84.55	57.12	1.12	41.75	-6.43
449.00	449.50	85.32	58.54	0.88	40.59	-6.37
449.50	450.00	84.60	56.67	1.46	41.87	-3.20
450.00	450.50	85.06	56.70	0.97	42.33	-2.73
450.50	451.00	83.55	53.17	1.58	45.25	-1.29
451.00	451.50	83.25	52.50	1.31	46.19	-7.66
451.50	452.00	84.55	57.36	1.51	41.13	-6.69
452.00	452.50	n/a	n/a	n/a	n/a	-5.90
452.50	453.00	83.88	56.80	1.85	41.34	1.93
453.00	453.50	84.34	59.32	1.31	39.36	-7.71
453.50	454.00	84.33	60.22	1.79	37.99	-8.27
454.00	454.50	84.70	60.18	1.69	38.14	-3.43
454.50	455.00	n/a	n/a	n/a	n/a	-6.81
455.00	455.50	85.30	56.18	1.37	42.45	-2.70
455.50	456.00	85.63	61.47	n/a	n/a	-1.32
456.00	456.50	85.44	61.16	1.40	37.44	-4.87
456.50	457.00	85.23	60.33	1.69	37.98	-4.06
457.00	457.50	85.34	62.58	1.89	35.53	-7.25
457.50	458.00	85.50	61.54	1.48	36.98	-8.17
458.00	458.50	84.90	58.88	1.42	39.70	-2.63
458.50	459.00	84.56	56.57	1.52	41.90	-1.59
459.00	459.50	82.89	52.65	1.67	45.69	-5.11
459.50	460.00	82.05	49.71	2.17	48.11	-2.38
460.00	460.50	83.39	56.27	2.07	41.66	-2.59

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
460.50	461.00	85.53	63.14	1.22	35.64	-7.46
461.00	461.50	86.43	62.98	2.22	34.81	-4.70
461.50	462.00	84.82	59.87	2.38	37.75	-4.65
462.00	462.50	84.78	60.50	2.13	37.37	-7.14
462.50	463.00	84.69	58.46	1.37	40.17	1.59
463.00	463.50	83.93	55.84	2.05	42.11	-3.56
463.50	464.00	84.51	58.80	1.35	39.86	-3.85
464.00	464.50	n/a	n/a	n/a	n/a	-6.43
464.50	465.00	85.02	62.13	1.43	36.44	-7.00
465.00	465.50	85.36	65.51	1.97	32.52	-7.27
465.50	466.00	85.69	65.21	1.82	32.97	-4.82
466.00	466.50	85.83	64.08	1.12	34.79	-7.42
466.50	467.00	85.65	64.47	1.25	34.28	-7.76
467.00	467.50	83.54	57.71	1.70	40.58	-1.81
467.50	468.00	84.41	60.14	1.46	38.41	-4.30
468.00	468.50	84.69	60.33	0.66	39.00	-7.11
468.50	469.00	83.54	55.91	1.41	42.68	-5.27
469.00	469.50	82.44	51.05	0.98	47.97	-1.14
469.50	470.00	83.16	52.84	0.83	46.33	-4.36
470.00	470.50	82.28	46.82	1.16	52.02	-2.28
470.50	471.00	81.95	48.79	1.18	50.03	-4.85
471.00	471.50	83.92	54.80	1.10	44.09	1.78
471.50	472.00	79.22	40.19	0.85	58.95	1.09
472.00	472.50	81.39	44.79	1.02	54.19	2.19
472.50	473.00	84.03	56.16	1.38	42.45	-4.27
473.00	473.50	80.60	46.84	1.04	52.12	3.58

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
473.50	474.00	82.89	53.85	1.51	44.65	-1.16
474.00	474.50	79.94	41.74	2.04	56.23	-1.70
474.50	475.00	82.50	48.25	1.75	50.00	-5.50
475.00	475.50	79.96	41.58	1.45	56.97	-3.04
475.50	476.00	82.01	47.55	0.94	51.51	-4.10
476.00	476.50	80.78	44.18	1.30	54.52	-2.19
476.50	477.00	79.38	41.67	1.87	56.46	-2.62
477.00	477.50	n/a	n/a	n/a	n/a	-6.52
477.50	478.00	83.33	48.49	2.30	49.21	-5.03
478.00	478.50	82.45	46.94	2.17	50.88	-7.58
478.50	479.00	81.82	46.56	1.31	52.13	-6.02
479.00	479.50	79.62	39.19	2.41	58.40	-7.51
479.50	480.00	83.89	54.86	2.33	42.82	-5.51
480.00	480.50	84.40	55.72	1.72	42.56	-3.43
480.50	481.00	84.14	56.74	0.59	42.67	-5.79
481.00	481.50	84.43	55.54	1.24	43.22	-7.51
481.50	482.00	83.65	52.62	1.90	45.47	-8.02
482.00	482.50	82.99	48.21	1.42	50.37	-8.32
482.50	483.00	83.92	50.17	1.42	48.40	-8.12
483.00	483.50	84.43	52.43	1.89	45.68	-9.39
483.50	484.00	82.32	46.92	0.89	52.19	-5.37
484.00	484.50	78.93	39.23	1.32	59.46	-7.27
484.50	485.00	82.46	49.22	0.10	50.68	-3.94
485.00	485.50	83.05	52.51	1.59	45.89	-3.85
485.50	486.00	84.98	61.06	2.56	36.38	-8.60
486.00	486.50	n/a	n/a	n/a	n/a	-4.12

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
486.50	487.00	84.49	57.58	0.93	41.49	-6.37
487.00	487.50	85.50	61.58	1.50	36.92	-6.95
487.50	488.00	n/a	n/a	n/a	n/a	-4.38
488.00	488.50	83.27	53.33	1.32	45.35	-5.79
488.50	489.00	n/a	n/a	n/a	n/a	-3.95
489.00	489.50	81.44	49.69	1.28	49.03	-1.14
489.50	490.00	83.62	57.62	1.18	41.20	-3.30
490.00	490.50	84.50	60.21	1.43	38.35	-3.37
490.50	491.00	85.02	60.41	1.65	37.94	-6.40
491.00	491.50	83.99	57.27	1.20	41.53	-6.20
491.50	492.00	81.73	48.17	1.65	50.17	-2.08
492.00	492.50	n/a	n/a	n/a	n/a	-2.40
492.50	493.00	82.59	51.46	1.40	47.14	-1.45
493.00	493.50	n/a	n/a	n/a	n/a	-1.90
493.50	494.00	81.63	47.93	0.64	51.43	-7.00
494.00	494.50	81.53	47.42	1.18	51.40	-2.57
494.50	495.00	n/a	n/a	n/a	n/a	-1.74
495.00	495.50	83.81	51.43	0.80	47.77	-6.28
495.50	496.00	84.41	53.31	1.48	45.21	-2.29
496.00	496.50	84.17	53.23	0.64	46.13	-6.63
496.50	497.00	82.91	49.15	1.41	49.44	-7.66
497.00	497.50	84.06	52.93	1.64	45.43	-1.65
497.50	498.00	83.65	54.47	1.51	44.02	-5.93
498.00	498.50	84.01	55.14	1.22	43.65	-5.27
498.50	499.00	n/a	n/a	n/a	n/a	-3.45
499.00	499.50	83.52	54.40	1.21	44.40	-6.36

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
499.50	500.00	83.07	54.45	0.89	44.66	-6.19
500.00	500.50	81.87	48.37	1.03	50.61	-5.73
500.50	501.00	83.45	56.00	0.16	43.84	-7.95
501.00	501.50	82.82	52.57	0.44	46.99	-4.89
501.50	502.00	82.89	52.18	1.85	45.97	-8.01
502.00	502.50	n/a	n/a	n/a	n/a	-7.42
502.50	503.00	81.15	46.43	0.64	52.92	-6.41
503.00	503.50	n/a	n/a	n/a	n/a	-2.60
503.50	504.00	82.82	51.50	1.06	47.44	-4.37
504.00	504.50	82.70	48.55	1.25	50.21	-5.07
504.50	505.00	81.64	47.24	1.01	51.75	-2.23
505.00	505.50	81.31	46.90	1.20	51.90	-2.09
505.50	506.00	80.24	44.86	1.08	54.06	-3.69
506.00	506.50	78.31	37.55	1.40	61.05	1.00
506.50	507.00	76.88	35.77	1.41	62.82	2.58
507.00	507.50	74.37	31.73	1.23	67.04	5.06
507.50	508.00	80.28	41.30	1.49	57.21	-1.90
508.00	508.50	79.66	41.24	1.14	57.61	-3.42
508.50	509.00	77.73	37.21	1.15	61.64	-1.74
509.00	509.50	78.04	37.33	1.08	61.59	1.80
509.50	510.00	79.51	42.42	0.93	56.65	-2.51
510.00	510.50	83.04	53.45	0.57	45.97	-7.56
510.50	511.00	83.99	58.71	0.97	40.32	-7.07
511.00	511.50	84.43	60.69	1.62	37.69	-5.98
511.50	512.00	84.04	59.46	1.44	39.10	-9.26
512.00	512.50	83.43	58.64	0.85	40.51	-8.04

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
512.50	513.00	81.63	50.36	1.06	48.58	-7.13
513.00	513.50	n/a	n/a	n/a	n/a	-3.73
513.50	514.00	n/a	n/a	n/a	n/a	-6.66
514.00	514.50	n/a	n/a	n/a	n/a	-1.05
514.50	515.00	n/a	n/a	n/a	n/a	-2.09
515.00	515.50	79.72	45.01	1.63	53.36	-2.20
515.50	516.00	78.72	41.86	1.32	56.82	-2.49
516.00	516.50	78.32	41.55	1.12	57.33	-3.01
516.50	517.00	77.90	43.91	1.33	54.76	-2.10
517.00	517.50	81.83	53.09	1.19	45.72	-4.56
517.50	518.00	83.69	58.62	1.89	39.49	-7.50
518.00	518.50	83.42	57.18	2.63	40.19	-4.54
518.50	519.00	81.56	52.34	1.05	46.61	-5.04
519.00	519.50	82.78	54.93	1.95	43.13	-2.94
519.50	520.00	82.36	53.53	2.01	44.46	-4.97
520.00	520.50	82.35	54.51	2.51	42.98	-4.12
520.50	521.00	82.85	54.84	1.77	43.39	-6.78
521.00	521.50	81.93	49.20	2.10	48.70	-5.66
521.50	522.00	82.47	54.33	2.11	43.55	-6.66
522.00	522.50	80.52	45.44	2.15	52.41	1.96
522.50	523.00	80.14	42.78	1.92	55.31	1.81
523.00	523.50	80.80	43.75	1.84	54.41	4.38
523.50	524.00	79.94	42.99	1.35	55.66	3.13
524.00	524.50	80.15	42.88	1.47	55.65	6.18
524.50	525.00	79.16	40.44	1.78	57.78	-3.14
525.00	525.50	75.23	31.16	1.62	67.22	1.47

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
525.50	526.00	69.88	23.89	1.56	74.54	16.10
526.00	526.50	70.75	25.64	1.90	72.46	25.52
526.50	527.00	78.79	37.64	2.25	60.11	3.05
527.00	527.50	n/a	n/a	n/a	n/a	-1.26
527.50	528.00	76.73	34.15	1.84	64.01	3.04
528.00	528.50	75.67	33.33	1.81	64.86	5.85
528.50	529.00	75.77	33.24	1.79	64.98	3.29
529.00	529.50	n/a	n/a	n/a	n/a	8.10
529.50	530.00	72.91	28.23	1.96	69.81	8.49
530.00	530.50	69.66	23.72	1.54	74.74	18.02
530.50	531.00	66.73	20.13	2.03	77.84	18.19
531.00	531.50	59.75	14.85	1.47	83.68	63.46
531.50	532.00	56.03	11.69	1.28	87.03	40.45
532.00	532.50	n/a	n/a	n/a	n/a	53.55
532.50	533.00	51.92	9.35	1.10	89.56	101.74
533.00	533.50	50.92	9.42	1.06	89.52	52.01
533.50	534.00	58.79	13.38	1.46	85.16	53.33
534.00	534.50	37.52	5.07	0.82	94.10	152.95
534.50	535.00	37.99	4.96	1.04	94.00	143.11
535.00	535.50	32.12	3.32	0.95	95.73	140.15
535.50	536.00	28.65	2.51	0.90	96.59	135.34
536.00	536.50	27.45	2.55	1.14	96.31	116.65
536.50	537.00	25.60	2.67	1.11	96.22	312.16
537.00	537.50	19.56	1.31	0.80	97.89	368.30
537.50	538.00	17.78	1.46	0.65	97.89	339.07
538.00	538.50	n/a	n/a	n/a	n/a	342.16

Top (cm)	Bot (cm)	Water (%)	Organics (%)	Carbonates (%)	Silicilastic (%)	Mag. Sus. (x10-6 SI)
538.50	539.00	14.55	2.54	0.62	96.83	342.53
539.00	539.50	n/a	n/a	n/a	n/a	342.00

Table III – Pollen counts for Spindly Pine Lake sediment core.

Depth	25cm	Depth	50cm	Depth	75cm	Depth	100cm
Pinus	233	Pinus	239	Pinus	242	Pinus	255
Picea	5	Picea	8	Picea	7	Picea	12
Betula	15	Betula	15	Betula	15	Betula	15
Alnus	10	Alnus	14	Alnus	18	Alnus	15
Populus	18	Populus	5	Populus	0	Populus	0
Juniperus	12	Juniperus	7	Juniperus	12	Juniperus	1
Salix	6	Salix	8	Salix	6	Salix	2
Artemsia	1	Artemsia	4	Artemsia	0	Artemsia	0
Poacea	0	Poacea	0	Poacea	0	Poacea	0
Other	0	Other	0	Other	0	Other	0
Total	300	Total	300	Total	300	Total	300
Lycop.	85	Lycop.	81	Lycop.	129	Lycop.	87

Depth	125cm	Depth	150cm	Depth	175cm	Depth	200cm
Pinus	252	Pinus	236	Pinus	170	Pinus	131
Picea	7	Picea	22	Picea	23	Picea	47
Betula	14	Betula	22	Betula	37	Betula	55
Alnus	15	Alnus	4	Alnus	39	Alnus	41
Populus	0	Populus	1	Populus	5	Populus	9
Juniperus	7	Juniperus	9	Juniperus	8	Juniperus	8
Salix	3	Salix	5	Salix	14	Salix	3
Artemsia	2	Artemsia	1	Artemsia	2	Artemsia	2
Poacea	0	Poacea	0	Poacea	0	Poacea	0
Other	0	Other	0	Ericacea	2	Ericacea	4
Total	300	Total	300	Total	300	Total	300
Lycop.	104	Lycop.	52	Lycop.	95	Lycop.	97

Depth	225cm	Depth	250cm	Depth	275cm	Depth	300cm
Pinus	121	Pinus	124	Pinus	20	Pinus	10
Picea	38	Picea	45	Picea	80	Picea	99
Betula	62	Betula	46	Betula	74	Betula	105
Alnus	52	Alnus	30	Alnus	61	Alnus	56
Populus	9	Populus	15	Populus	6	Populus	5
Juniperus	5	Juniperus	20	Juniperus	26	Juniperus	8
Salix	6	Salix	2	Salix	10	Salix	6
Artemsia	6	Artemsia	0	Artemsia	10	Artemsia	6
Poacea	0	Poacea	15	Poacea	10	Poacea	5
Ericacea	1	Ericaceae	3	Ericacea	3	Other	0
Total	300	Total	300	Total	300	Total	300
Lycop.	111	Lycop.	99	Lycop.	120	Lycop.	136

Depth	325cm	Depth	350cm	Depth	375cm	Depth	400cm
Pinus	13	Pinus	5	Pinus	1	Pinus	0
Picea	188	Picea	144	Picea	156	Picea	168
Betula	41	Betula	62	Betula	79	Betula	70
Alnus	46	Alnus	53	Alnus	27	Alnus	30
Populus	1	Populus	5	Populus	1	Populus	2
Juniperus	3	Juniperus	13	Juniperus	13	Juniperus	15
Salix	3	Salix	11	Salix	17	Salix	11
Artemsia	3	Artemsia	5	Artemsia	2	Artemsia	4
Poacea	0	Poacea	2	Poacea	4	Poacea	0
Ericacea	2	Other	0	Other	0	Other	0
Total	300	Total	300	Total	300	Total	300
Lycop.	56	Lycop.	78	Lycop.	96	Lycop.	73

Depth	425cm	Depth	450cm	Depth	475cm	Depth	500cm
Pinus	0	Pinus	0	Pinus	0	Pinus	0
Picea	206	Picea	190	Picea	100	Picea	2
Betula	55	Betula	50	Betula	97	Betula	213
Alnus	20	Alnus	31	Alnus	46	Alnus	32
Populus	1	Populus	2	Populus	0	Populus	0
Juniperus	14	Juniperus	3	Juniperus	4	Juniperus	4
Salix	4	Salix	8	Salix	21	Salix	16
Artemsia	0	Artemsia	10	Artemsia	14	Artemsia	18
Poacea	0	Poacea	4	Poacea	13	Poacea	15
Other	0	PolyPenta	2	Polypenta	5	Other	0
Total	300	Total	300	Total	300	Total	300
Lycop.	59	Lycop.	94	Lycop.	103	Lycop.	96

Table IV – Age of mature trees surrounding Spindly Pine Lake.

Tree	Age (Years)
SP01	89
SP02	85
SP03	80
SP04	84
SP05	101
SP06	85
SP07	98
SP08	94
SP09	86
SP10	89
SP11	78
SP12	84
SP13	65
SP14	60
SP15	61
SP16	73
SP17	85
SP18	80
SP19	123
SP20	179
SP21	90
SP22	69